Fisheries

Spencer Gulf Prawn *Penaeus* (*Melicertus*) *latisulcatus* Fishery 2013/14

C. J. Noell and G. E. Hooper

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July 2015

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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Front cover photo: Spencer Gulf prawn trawl vessel (reproduced with permission from S. Clark).

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EXECUTIVE SUMMARY

This report updates the assessment for the Spencer Gulf Prawn Fishery (SGPF) with information obtained from the 2013/14 fishing year. The aims of this report were to: 1) provide a synopsis of information for the fishery; 2) review the performance of the fishery; 3) determine the current status of the resource and identify limitations with the assessment; and 4) identify future research needs.

The annual harvest of 1,675 t for 2013/14 was marginally (1%) below the 1,699 t harvested in 2012/13 and within the historic range (~1,600-2,400 t). While an increase in effort (19,901 h, 5% increase from 2012/13) resulted in the lowest catch per unit effort (CPUE) in more than a decade (84.2 kg h^{-1}), CPUE was still above the limit reference point (LRP, 80 kg h^{-1}). A declining trend in harvest from the normally-productive Wallaroo and Middlebank/Shoalwater regions was offset in 2013/14 by increased harvest in the (traditionally) lightly-fished North region.

Mean survey catch rate of ‘adult’ prawns (based on size-grade categories) from the November survey translated into a 450 t pre-Christmas catch cap for the fleet, most of which was harvested. As indices of current and future biomass, the mean catch rate for all prawns and ‘recruits’, respectively, were above lower thresholds for the November and April surveys but fell below these thresholds for the February survey. The lower thresholds in the 2007 Management Plan were designed to maintain the biomass within historic levels and assumed to be above sustainable limits. In accordance with the harvest strategy in the 2007 Plan, standard fishing strategies were adopted throughout the 2013/14 fishing year. With respect to other key performance indicators, egg production was the highest recorded for November surveys, and recruitment index from the February survey was above the LRP.

A new management plan for the SGPF was implemented at the start of the 2014/15 fishing year. Although not in operation in 2013/14 for fishing strategy development, the 2014 Management Plan was used in this report to evaluate the fishery’s performance and determine end-of-year stock status. All seven performance indicators were above their LRPs. Three of these (mean survey catch rate, recruitment and egg production) demonstrated substantial improvement from 2012/13 levels. The 2014 Management Plan features a revised harvest strategy that addresses limitations of the previous harvest strategy by: 1) establishing a LRP that determines the level below which the fishery is considered recruitment overfished; 2) outlining how stock status is determined based on the weighted mean catch rate for adult prawns from all three stock assessment surveys; and 3) describing a recovery strategy should the fishery ever become recruitment overfished.

Based on application of the revised harvest strategy, the SGPF is not considered to be overfished and the current level of fishing mortality is unlikely to cause the stock to become recruitment overfished. Therefore, the resource supporting the SGPF is classified as a ‘sustainable stock’.

Future research is identified within a four-year research scope, and includes annual determination of stock status, annual surveys of juvenile abundance and disease monitoring, biennial stock assessment reports, and ‘additional’ research projects focused on stock assessment development and ecosystem monitoring during non-assessment years.

1. INTRODUCTION

1.1. Overview

This report is the tenth in a series that has been updated annually since 2003 as part of the South Australian Research and Development Institute (SARDI) Aquatic Sciences' ongoing assessment program for the Spencer Gulf Prawn Fishery (SGPF) (Carrick 2003; Dixon *et al.* 2005; 2007; Dixon and Hooper 2008; Dixon *et al.* 2009; 2010; 2012; 2013; Noell *et al.* 2014). The report updates the assessment for the SGPF (Noell *et al.* 2014) with information obtained from the 2013/14 fishing year. The aims of this report were to: 1) provide a synopsis of information available for the fishery; 2) review the performance of the fishery; 3) determine the current status of the resource; and 4) identify future research needs.

1.2. Description of the fishery

1.2.1. Fishery location

There are three commercial prawn fisheries in South Australia: 1) SGPF; 2) Gulf St Vincent Prawn Fishery (GSVPF); and 3) West Coast Prawn Fishery (WCPF). All exclusively target the western king prawn (*Penaeus (Melicertus) latisulcatus*). The SGPF is the largest in terms of total area (22,367 km^2), production (latest 10-year mean: 1,907 t), and number of licence holders/vessels (39).

The SGPF encompasses the waters of Spencer Gulf north from Cape Catastrophe, Eyre Peninsula (34°9.119′S, 136°00.184′E) to Cape Spencer, Yorke Peninsula (35°17.993′S, 136°52.835′E). It comprises ten regions that represent the main trawl grounds of the fishery. These regions are subdivided into a total of 125 commercial fishing blocks (Figure 1.1).

1.2.2. The Spencer Gulf environment

Spencer Gulf is a large shallow body of water with a mean depth of 23 m, and a maximum depth of 87 m at its entrance in the south (Figure 1.2). The predominant sediment is sand and mud, and seagrass habitats are common at depths less than 10 m.

Spencer Gulf is situated in a semi-arid climate where annual evaporation far exceeds precipitation. Due to excessive evaporation, the gulf is classified as an inverse estuary, attaining salinities that are greater than the surrounding ocean and increase towards the head of the gulf (Nunes and Lennon 1986). Inverse estuaries are characterised by an outflow of dense, saline water in bottom layers and an inflow of oceanic water in surface layers. In Spencer Gulf, this density-driven circulation is influenced by the earth's rotation, such that the dense saline outflows occur along the eastern side, whereas surface inflows occur along the western side (Kämpf *et al.* 2009). This gives rise to an overall clockwise circulation pattern.

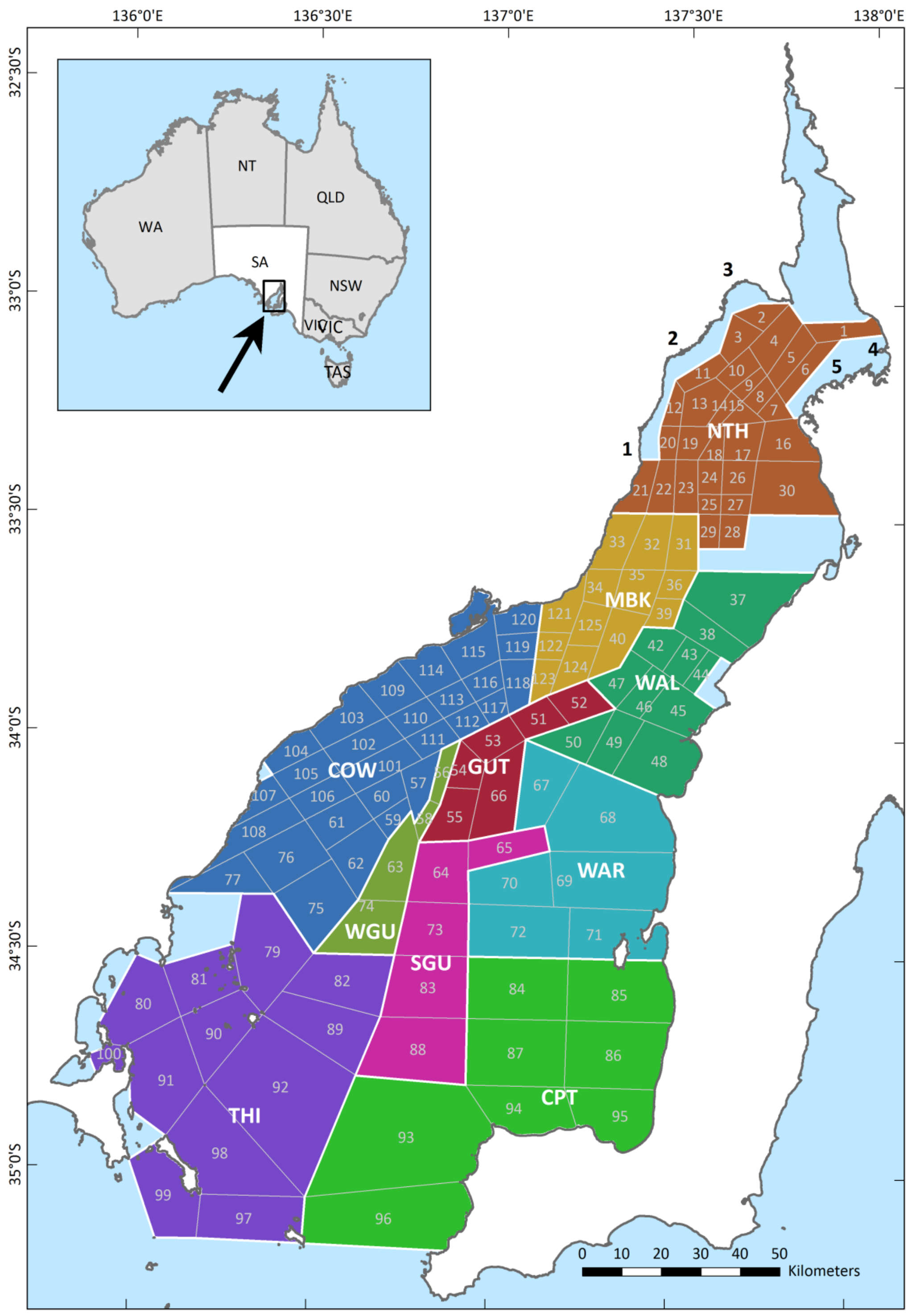


Figure 1.1. Fishing blocks and regions of the Spencer Gulf Prawn Fishery. Inset map shows location of the fishery in South Australia. Abbreviations: COW, Cowell; CPT, Corny Point; GUT, Gutter; MBK, Middlebank/Shoalwater; NTH, North; SGU, South Gutter; THI, Thistle; WAL, Wallaroo; WAR, Wardang; WGU, West Gutter. Also shown are key nursery sites referred to in the report: 1, Spit; 2, Mount Young; 3, False Bay; 4, Port Pirie; 5, Fifth Creek.

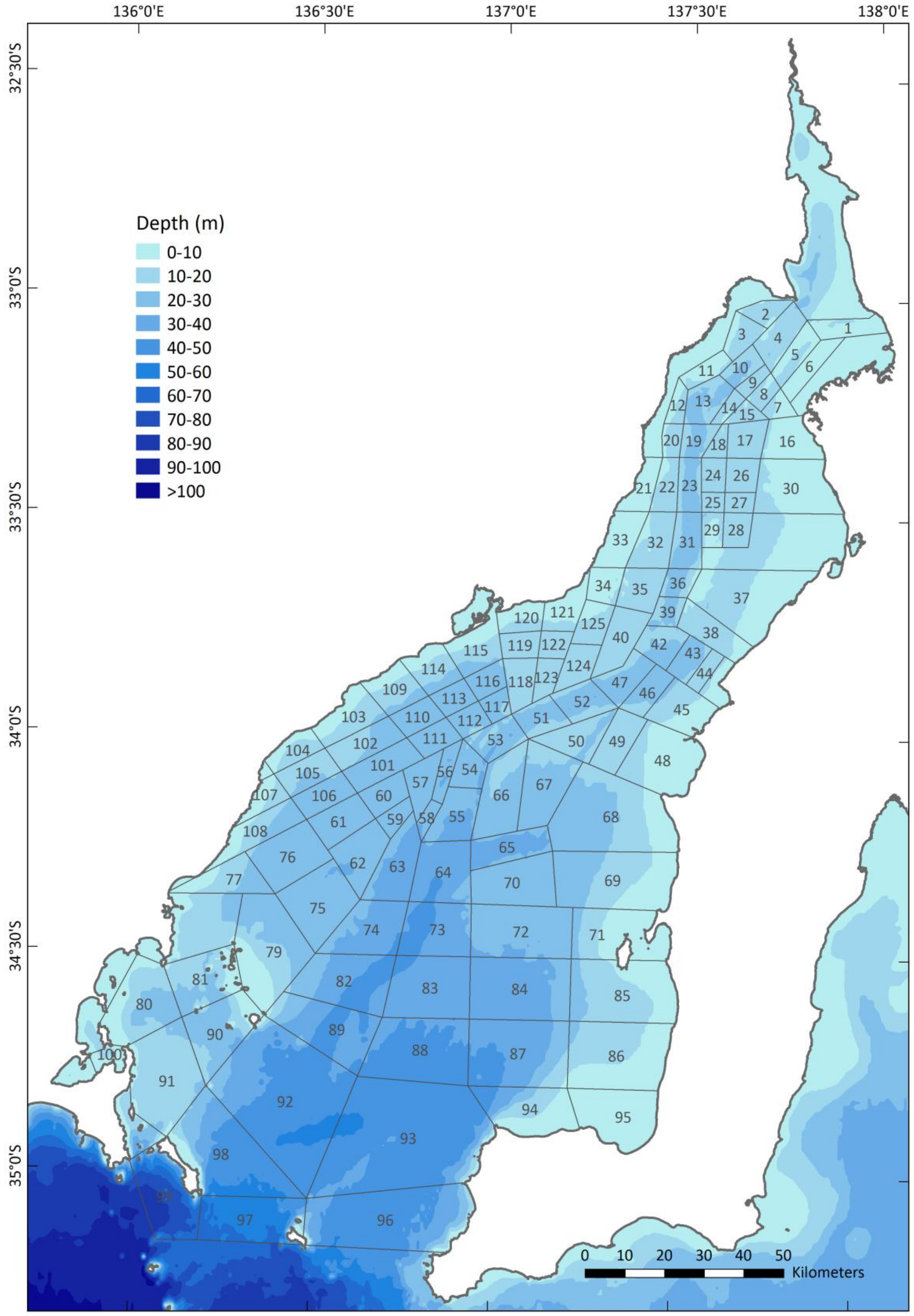


Figure 1.2. Bathymetry of Spencer Gulf.

Sea surface temperatures (SST) in the South Australian gulfs are lower and more variable than in northern fisheries that target the western king prawn (e.g. Broome and Shark Bay in Western Australia, Figure 1.3). In Spencer Gulf, SST fluctuates seasonally between ~12°C and ~24°C (Nunes and Lennon 1986) and, in summer months, is characterised by warmer SST in the north, cooler surface waters in the south, and considerably lower temperatures in the surrounding open ocean (Figure 1.4).

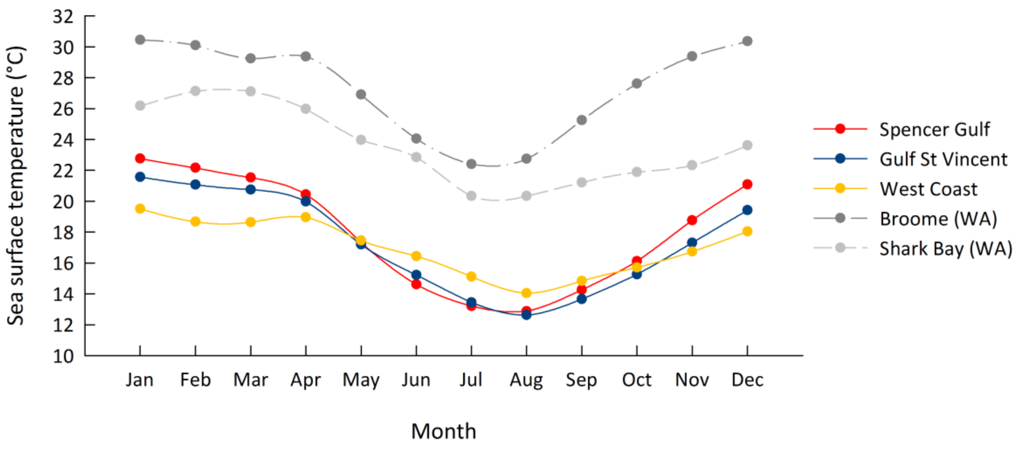


Figure 1.3. Mean monthly sea surface temperatures in 2012 for the South Australian and Western Australian (WA) prawn fisheries that target western king prawn.

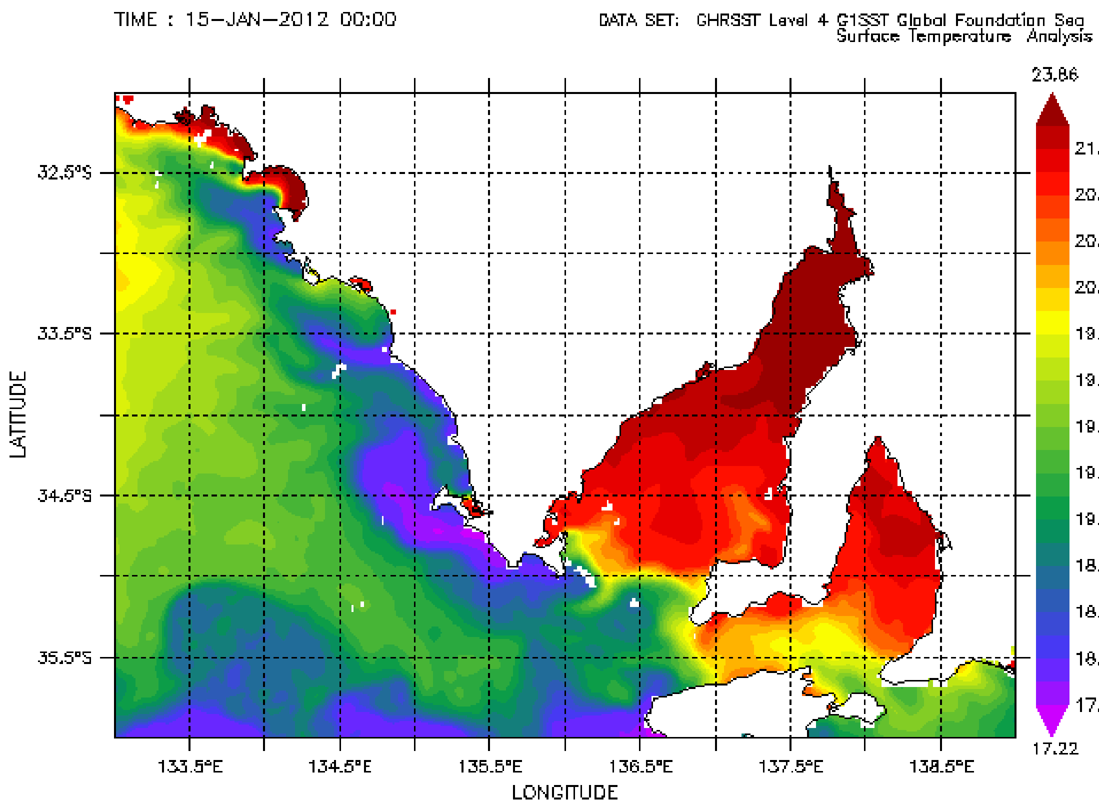


Figure 1.4. Sea surface temperatures (°C) of the continental shelf and gulf waters of South Australia during January 2012. Source: NASA (2013).

1.2.3. Nursery areas

In South Australian waters, juvenile western king prawns occur predominately on intertidal sand and mudflats, generally located between shallow subtidal/intertidal seagrass beds and mangroves higher on the shoreline (PIRSA 2003). In Spencer Gulf, the density of juveniles was found to be significantly greater in the mid-intertidal zone compared to lower and upper zones (Roberts *et al.* 2005), while in Gulf St Vincent, densities of juveniles were similar across the intertidal zones (Kangas and Jackson 1998).

Based on Bryars' (2003) inventory of important coastal fishery habitats in South Australia, Dixon *et al.* (2013) estimated that 76% of the Spencer Gulf coastline comprises appropriate habitat for prawn nursery areas, i.e. tidal flat only (51%) and mangrove forests[1] (25%) (Table 1.1). Most of these habitat types are in the northern region of the gulf. Juvenile prawn surveys have shown that the greatest abundance of juveniles generally occurred at sites within this region (Roberts *et al.* 2005).

Table 1.1. Fishery habitat areas (Bryars 2003) and the estimated distance and proportion of coastline of tidal flat and mangrove forest for each of South Australia's prawn fisheries.

Fishery	Fishery habitat areas	Coastline (km)	Tidal flat only		Mangrove	
			km	%	km	%
Spencer Gulf	15	992	508	51	245	25
Gulf St Vincent	11	551	225	41	79	14
West Coast	16	1,310	310	24	45	3

In a study of penaied prawn fisheries around the world, Pauly and Ingles (1999) demonstrated a significant relationship between mangrove area and fisheries production, thus supporting the widely held view that intertidal vegetation (particularly mangroves) plays a major role in penaeid prawn recruitment.

1.2.4. Commercial fishery

The earliest record of the western king prawn in Spencer Gulf was from experimental trawling in 1909 by FIS *Endeavour* (Carrick 2003). Commercial prawn trawling was attempted in 1948, but the first commercial quantity of prawns was not harvested until October 1968 (Carrick 2003).

Prawns are harvested at night using demersal otter trawls configured with two nets (Figure 1.5). It has become standard practice in the fishery to use 'crab bags' to exclude mega-fauna by-catch (Figure 1.6), 'hoppers' for efficient sorting of the catch and rapid return of by-catch (Figure 1.5), and 'graders' to sort the prawns into marketable size categories (Figure 1.5). The entire Spencer Gulf fleet comprises 'factory vessels', which process the catch on-board.

[1] Mangrove forest always overlapped with tidal flat but is considered separate to habitat comprising only tidal flat.

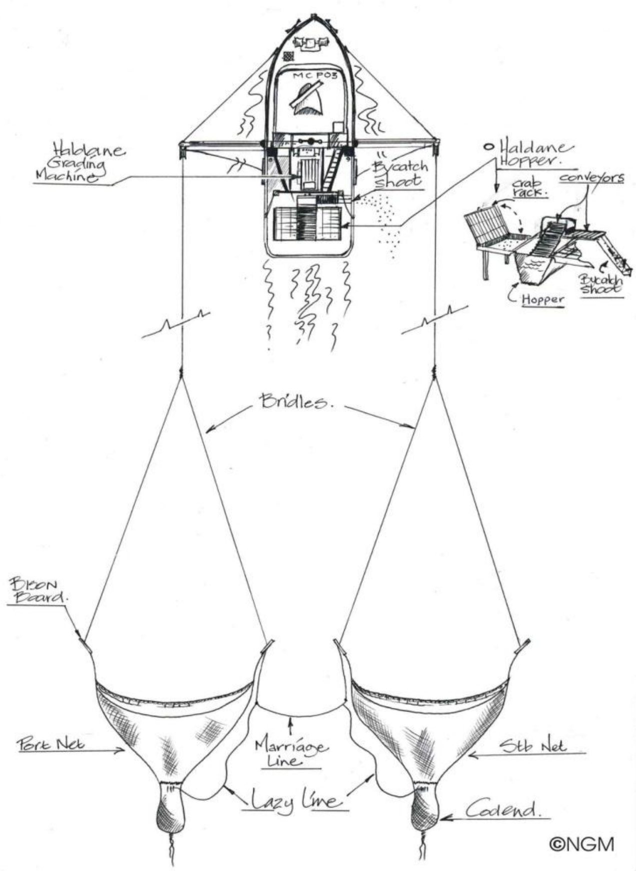


Figure 1.5. Double rig trawl net configuration, hopper and size grader used in the Spencer Gulf Prawn Fishery. Source: Carrick (2003).

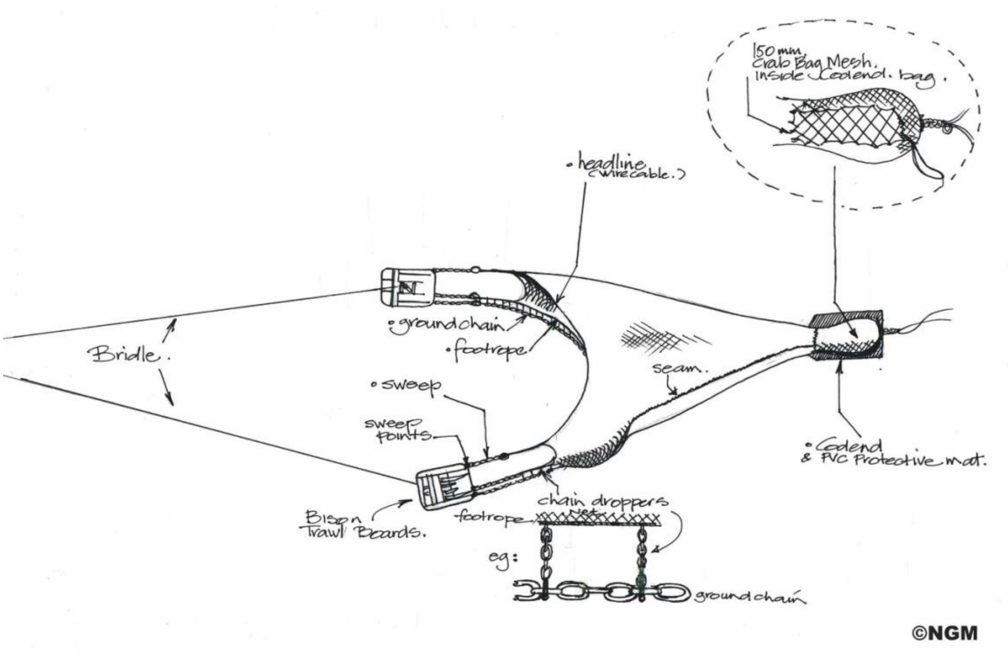


Figure 1.6. Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Source: Carrick (2003).

The SGPF is the third most valuable prawn fishery in Australia ($27.4M in 2012/13) behind Queensland's East Coast Otter Trawl Fishery ($86.2M in 2012) (Anon. 2013) and the Commonwealth's Northern Prawn Fishery (NPF: $64.7M in 2012) (Woodhams and George 2013). In terms of value per licence holder, the SGPF is ranked second (39 licences, $0.70M per licence) behind the NPF (52 licences, $1.24M per licence).

South Australia's prawn fisheries are the only substantial single-species prawn fisheries in Australia. However, it is not the only fishery to target the western king prawn: 1,075 t (68% of the total prawn harvest) and 157 t (55%) of western king prawns were caught from Western Australia's Shark Bay and Exmouth Gulf prawn fisheries, respectively, in 2012 (Sporer *et al.* 2013a; Sporer *et al.* 2013b).

The SGPF's reputation as one of the world's best managed fisheries (Gillett 2008) was further enhanced in 2011 when it became the first prawn trawl fishery in the Asia-Pacific region to gain accreditation by the Marine Stewardship Council for its ecologically sustainable fishing practices.

1.2.5. Recreational, traditional and illegal catch

Under current fisheries legislation, it is prohibited for any person to take western king prawns from waters less than 10 m in depth. As prawn trawl nets can only be used by the commercial fishing sector, the catch by the recreational sector and Aboriginal traditional fishing is negligible (Anon. 2003). The illegal take of prawns is assumed to also be negligible.

1.3. Management of the fishery

1.3.1. Legislation

The SGPF is managed by Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture in accordance with the legislative framework provided within the *Fisheries Management Act 2007*, *Fisheries Management (General) Regulations 2007* and *Fisheries Management (Prawn Fisheries) Regulations 2006*.

1.3.2. Consultative process and co-management

Under the previous *Fisheries Act 1982*, Fisheries Management Committees (FMCs) were established to provide a consultative forum for commercial industry and other stakeholders to work with government in relation to each commercial fishery. Since the introduction of the *Fisheries Management Act 2007*, FMCs were disbanded and a single expertise-based board, the Fisheries Council, was established to provide high-level advice to the Minister and perform a number of important functions, including the promotion of co-management in fisheries. Under this framework, industry associations have taken on greater responsibility for running the consultative process between industry and PIRSA. These changes have provided greater opportunities for well organised, representative fishing bodies, such as the Spencer Gulf and West Coast Prawn Fishermen's Association (SGWCPFA), to increase their role in co-management for a range of benefits (e.g. reduce administrative costs, stewardship of the resource).

1.3.3. Current management arrangements for the commercial sector

Management arrangements in the commercial sector of the SGPF have evolved since the fishery began in the late 1960s (Table 1.2). Now, the SGPF is a limited entry fishery with 39 licensed operators. Trawling activity is prohibited during daylight hours and in waters less than 10 m in depth. Effort is restricted through a range of input controls: i.e. spatial and temporal closures, vessel size and power, and configuration of trawl gear, including type and number of nets towed, maximum headline length and minimum mesh size (Table 1.3).

Table 1.2. Major management milestones over the history of the Spencer Gulf Prawn Fishery.

Year	Management milestone
1968	Licences restricted. Trawling prohibited in waters <10 metres. Commercial catch and effort recording began.
1969	*Prawn Resources Regulations 1969* established. Spencer Gulf divided into two zones.
1971	Spencer Gulf zones removed
1974	Spatial closure north of Point Lowly introduced
1976	Licences restricted to 39
1981	Spatial closure adjacent to Port Broughton introduced
1982	*Fisheries Act 1982* introduced
1984	*Scheme of Management (Spencer Gulf Prawn Fishery) Regulations 1984* introduced
1991	*Fisheries (Scheme of Management – Prawn Fisheries) Regulations 1991* introduced
1995	*Fisheries (Management Committees) Regulations 1995* introduced
1998	First management plan implemented
2006	*Fisheries Management (Prawn Fisheries) Regulations 2006* introduced
2007	Second management plan implemented. *Fisheries Management Act 2007* introduced.
2014	Third management plan implemented (at the start of the 2014/15 fishing year)

For the purpose of this report, the 'fishing year' is defined as the 12-month period from 1 October to 30 September the following year. However, fishing generally only occurs during the months of November and December and from March to June between the last and first quarter of the moon (i.e. during waning crescent and waxing crescent phases either side of the dark moon). These fishing areas are administered via a Section 79 Notice under the *Fisheries Management Act 2007*.

Table 1.3. Current management arrangements for the Spencer Gulf Prawn Fishery.

Management control	Specification
Target species	Western king prawn *Penaeus (Melicertus) latisulcatus*
Permitted by-product species	Slipper lobsters *Ibacus* spp., southern calamari *Sepioteuthis australis*
Limited entry	Yes
Number of licences	39
Corporate ownership of licences	Yes
Licence transferability	Yes
Minimum depth for trawling	10 m
Method of capture	Demersal otter trawl
Trawl net configuration	Single or double rig
Maximum total headline length	29.26 m
Minimum mesh size	4.5 cm
Maximum length of vessel	22 m
Maximum engine capacity	336 kW
Catch and effort data	Daily logbook submitted monthly
Recreational fishery	Restricted to depths >10 m, hand nets only

1.3.4. Management plan

MacDonald (1998) developed the first management plan for the Spencer Gulf and West Coast prawn fisheries. Almost a decade later, Dixon and Sloan (2007) prepared an updated management plan specific to the SGPF; this was the management plan in operation during the 2013/14 fishing year (hereafter referred to as the ‘2007 Plan’). As such, the fishing strategies developed were in line with the harvest strategy in that plan. A third management plan for the fishery was introduced after the completion of the 2013/14 fishing year (PIRSA 2014; hereafter referred to as the ‘2014 Plan’). Although not in operation during the 2013/14 fishing year, the 2014 Plan highlighted a revised harvest strategy that incorporated, for the first time, a method for determining annual stock status. Given that the status was designed to influence fishing strategy development in the following year, this report includes the determination of the end-of-year stock status for 2013/14.

The 2014 Plan identified four goals and associated objectives and strategies within a decision-making framework (PIRSA 2014). The primary goal of the 2014 Plan was to: 1) maintain an ecologically sustainable prawn biomass; while other goals were to 2) ensure optimal utilisation and equitable distribution; 3) protect and conserve aquatic resources, habitats and ecosystems; and 4) enable effective and participative management of the fishery.

1.3.5. Fishing strategy development

The aim of the fishing strategy in the SGPF is to maximise economic yield in an ecologically sustainable manner by limiting effort spatially and temporally. The ‘nature’ of the fishing strategy is defined in both 2007 and 2014 Plans as ‘conservative’, ‘standard’ or ‘increasing’, and is determined following each stock assessment survey through application of harvest decision rules.

Two types of surveys are conducted: 1) three fishery-independent (stock assessment) surveys in November, February, and April; and 2) fishery-dependent (spot) surveys at various times throughout the fishing year. ‘Fishing periods’ are defined as the periods in which fishing has taken place separated by the end of the lunar period or a survey. There are generally six or seven fishing periods in a fishing year. The fishing strategy for each fishing period is based on preceding stock assessment survey results.

The area(s) of the gulf opened to fishing are dependent on the nature of the strategy and associated criteria for minimum prawn size. The strategy aims to reflect the current status of the resource and ensure that the catch and effort levels are appropriate to ensure sustainability. For example, a low survey mean total catch rate indicates a low biomass, and may lead to a conservative strategy, which aims to promote recovery of catch rates to historic levels. During the fishing period, the industry ‘Committee at Sea’ (CAS) monitors the catch of the fleet with respect to size and catch criteria of the fishing strategy and, where necessary, or when they believe it is in the interests of longer-term yields for the fishery, will reduce the size of the area fished, postpone fishing, or cease fishing altogether.

November and December fishing periods are primarily restricted to a total catch cap for the fleet, whereas fishing periods from February to June are restricted by a minimum prawn size that relates to the fishing strategy and time of the year. Once the nature of the strategy has been determined following a stock assessment survey, the decision rules and criteria of that strategy remain in place until the next stock assessment survey is completed.

The potential for external factors to have a substantial influence on survey catch rates is recognised in the harvest strategies of both the 2007 and 2014 Plans. In the 2007 Plan, which was in operation for the 2013/14 fishing year, a conservative strategy was mandatory only when mean total catch rate or the catch rate of 'recruit'[2] prawns did not fall below its lower threshold over two consecutive surveys. These harvest decision meta-rules were revised in the 2014 Plan such that a conservative strategy is mandatory only when the mean catch rate of 'adult' or 'recruit' prawns falls below its reference point over two or three consecutive surveys, respectively. In both management plans, the lower threshold or reference point does not imply overfishing; rather it represents the lower range of historic levels, which are above the sustainable limit, and can therefore be considered an economic limit.

1.3.6. Performance indicators

The extent to which the fishery achieves goals and objectives of the Management Plan is traditionally assessed using a combination of performance indicators (PIs). The key biological and management PIs of the 2007 and 2014 Plans are presented in Table 1.4 and Table 1.5, respectively. Each PI is measured against a limit reference point (LRP), which defines the acceptable level. If the LRP is not achieved for any PI, measures to improve performance must be developed in accordance with the management response outlined in the Management Plan. Whilst measures against the PIs in the 2007 Plan are provided in the Results for comparison with previous years, measures against the PIs in the 2014 Plan will be used to evaluate the fishery's performance from this report onwards.

Table 1.4. Key performance indicators and limit reference points (or acceptable levels) in the 2007 Management Plan for the Spencer Gulf Prawn Fishery (Dixon and Sloan 2007).

Performance indicator	Limit reference point / acceptable level
1. Recruitment index ($\sqrt{\text{recruits nm}^{-1}}$) *	>35
2. Total commercial catch	>1,800 t
3. Mean commercial CPUE	>80 kg h^{-1}
4. % vessel nights with mean size >280 pp7kg	<2%
5. Indices of future and current biomass (defined in the 2007 Plan)	Neither index is below lower threshold levels in two consecutive surveys

* For calculation of the recruitment index, 'recruits' are defined as male prawns <33 mm CL and female prawns <35 mm CL.

[2] For the purpose of fishing strategy development, 'adult' and 'recruit' prawns are based on commercial size-grade categories, where adult prawns are made up of grades with 20 or fewer prawns per pound and recruit prawns are made up of grades with more than 20 prawns per pound.

Table 1.5. Key performance indicators and reference points in the 2014 Management Plan for the Spencer Gulf Prawn Fishery (PIRSA 2014).

Performance indicator		Limit reference point
1.	Weighted mean survey catch rate of adult prawns	≥2.5 lb min^{-1}
2.	Recruitment index $(\sqrt{\text{recruits nm}^{-1}})$ *	>35
3.	Mean egg production	>500 million eggs trawl-$hour^{-1}$
4.	Mean commercial CPUE	>80 kg trawl-$hour^{-1}$
5.	Return of commercial daily logbooks for all licences and all nights fished	100%
6.	Update of strategic research plan	Annually
7.	Fishery-independent surveys conducted to inform annual status	All three surveys

* For calculation of the recruitment index, 'recruits' are defined as male prawns <33 mm CL and female prawns <35 mm CL.

1.4. Biology of the western king prawn

1.4.1. Distribution and taxonomy

The western king prawn is distributed throughout the Indo-west Pacific (Grey *et al.* 1983). Its distribution in South Australia is unique, as it is at its lowest temperature range, restricted to waters of Spencer Gulf, Gulf St Vincent and along the West Coast. King (1977), Sluczanowski (1980) and Carrick (1982; 1996) provide detailed accounts of its distribution in Spencer Gulf.

The western king prawn is a benthic species that prefers sandy areas to seagrass or vegetated habitats (Tanner and Deakin 2001). Juvenile and adult prawns show a strong diel behavioral pattern of daytime burial and nocturnal activity (Rasheed and Bull 1992; Primavera and Lebata 2000). Strong lunar and seasonal differences in activity are also exhibited, where prawn activity (and catchability) is greater during the new (dark) moon phase of the lunar cycle and warmer months.

Abundance of the western king prawn within the gulfs and estuaries is also influenced by salinity, where higher abundances are associated with salinities above 30‰ (Potter *et al.* 1991). In other physiological studies on this species, optimal salinity ranged from 22-34‰, with 100% mortality occurring at salinities <10‰ (Sang and Fotedar 2004). Important nursery areas in Western Australia and South Australia are characterised as being hypersaline (35-55‰) (Carrick 1982; Penn *et al.* 1988), suggesting that juvenile western king prawns are efficient osmoregulators at high salinities.

Originally classified as *Penaeus latisulcatus* (Kishinouye, 1896), Pérez Farfante and Kensley (1997) proposed a taxonomic revision of the western king prawn by raising former sub-genera in the genus *Penaeus* to generic rank, thus replacing *Penaeus* with (the previously sub-genus) *Melicertus* (i.e. *Melicertus latisulcatus*). Recently, Flegel (2007) revised the taxonomic name to *Penaeus (Melicertus) latisulcatus*. A smaller penaeid, *Metapenaeopsis crassima*, occurs in Spencer Gulf but is of no commercial value.

1.4.2. Reproductive biology

In Spencer Gulf, adult western king prawns aggregate, mature, mate and spawn in deep water (>10 m) between October and April, with the main spawning period being earlier in the fishing year

(October to January), peaking in November (SARDI, unpublished data). A minimum temperature of 17°C is required for the western king prawn to spawn in Western Australia (Penn 1980), and the peak spawning period for Queensland populations is between June and July when water temperature drops below 25°C (Courtney and Dredge 1988). While the temperature range for spawning of western king prawn (17-25°C) generally occurs from November to May in Spencer Gulf, the majority of spawning in the gulf is restricted to earlier in the fishing year, which is likely to be associated with optimising reproductive success from shorter larval durations and higher larval survival at that time of year (Roberts *et al.* 2012) (see Section 1.4.3).

During mating the male transfers a sperm capsule (spermatophore) to the female reproductive organ (thelycum). The success of insemination depends on the female having recently moulted. Ovary development is followed by spawning of fertile eggs during a single intermoult period (Penn 1980), where fertilisation presumably occurs immediately prior to, or on release of, the eggs by the female.

The sex composition of western king prawns caught in Western Australia was shown to change to that of a female-biased catch during the peak spawning period, attributed to higher catchability of females due to food requirements and increased foraging during ovarian development (Penn 1976; 1980). Similarly, female-biased populations of western king prawn were observed during November and December in Gulf St Vincent (Svane 2003; Svane and Roberts 2005).

The proportion of reproductively mature female western king prawns increases with size. In Spencer Gulf, Carrick (2003) defined the relationship between proportion maturity (P) and carapace length (CL, in mm) with the logistic model:

$$P = 8.3 \times 10^{-6} + \left\{ 1 \middle/ \left[1 + e^{-0.277(CL - 36.45)} \right] \right\},$$

where the length at which 50% of the female population are mature (CL_{50}) is estimated at 36.5 mm (Figure 1.7). While females can mature at a small size, differences between tropical and temperate populations are apparent. The smallest ripe female recorded in Western Australian populations was 29 mm CL (Penn 1980), while in Spencer Gulf, the smallest ripe female was 24 mm CL (SARDI, unpublished data). Insemination rate affects fertilisation success and increases with size. Courtney and Dredge (1988) showed in Queensland populations that ~50% of females were inseminated at 34 mm CL, while ~95% were inseminated at 42 mm CL.

There are no data on the fecundity of the western king prawn in Spencer Gulf, however, fecundity increases exponentially with carapace length in populations from Gulf St Vincent (M. Kangas unpublished, cited in Carrick 2003) and Shark Bay (Penn 1980) (Figure 1.8). Thus, larger prawns make a greater contribution to total egg production due to greater insemination rates and fecundity (Penn 1980; Carrick 1996).

For the eastern king prawn (*P. plebejus*), females greater than 50 mm CL contribute little to egg production, with the bulk of the eggs produced by prawns in the size range of 35-48 mm CL (Courtney *et al.* 1995). Such ovarian senescence has not been documented for the western king prawn.

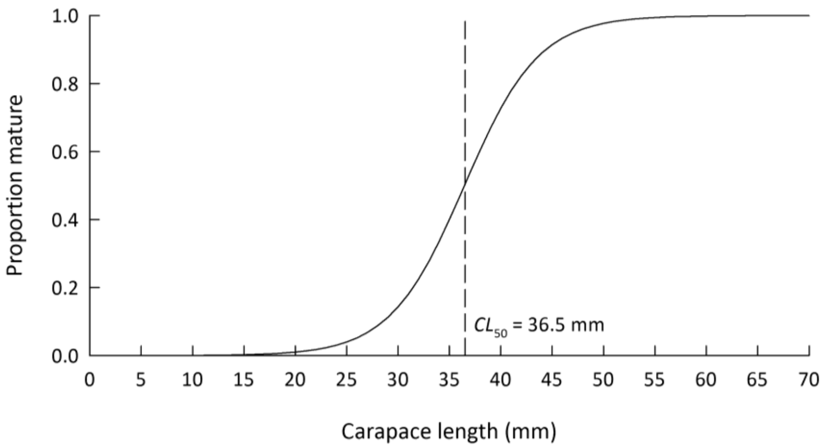


Figure 1.7. Logistic relationship between carapace length and sexual maturity for female western king prawns in Spencer Gulf.

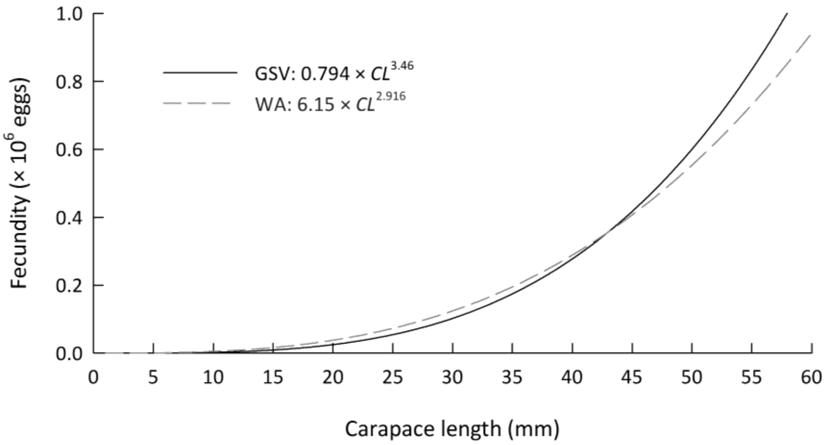


Figure 1.8. Relationship between carapace length and fecundity for female western king prawns in Gulf St Vincent (GSV) and Shark Bay, Western Australia (WA; Penn 1980).

Spawning frequency for the western king prawn appears to be related to moulting frequency, as no recently moulted females were found with well-developed (Stage 3 or 4) ovaries (Penn 1980; Courtney and Dredge 1988), females generally lose spermatophores with the exuvae at moult (Penn 1980), and the mean interval for both moulting and spawning was the same in tagging experiments (Penn 1980). The mean moulting interval for mature untagged females in Western Australian populations during the spawning season was estimated at 30 to 40 days (Penn 1980).

There are three lines of evidence supporting the concept of multiple spawning: 1) spent ovaries (Stage 5) are difficult to identify since the rapid recommencement of ovary development meant they were often classified as developing (Stage 2) (Penn 1980; Courtney and Dredge 1988); 2) in an experiment where ripe females were tagged and released, many recaptured individuals were found to have spawned and moulted, and had ovaries at an early stage of development during the same season (Penn 1980); and 3) artificial spawning of *P. orientalis* in aquaria, using eyestalk ablation, demonstrated the multiple spawning capacity of penaeids (Arnstein and Beard 1975). In addition to multiple spawning events within a season, females are likely to spawn for multiple seasons based on the observation of a large proportion of females in different size cohorts being reproductively active during the spawning season (Penn 1980).

Prawn reproduction can be adversely affected by parasite load and disease status. Courtney *et al.* (1995) showed that parasitisation by bopyrid isopods affected the reproductive output of the eastern king prawn. Bopyrid isopods have been observed to parasitise western king prawn (Roberts *et al.* 2010). Viral infections have been shown to affect moulting and reproduction in another penaeid, the redleg banana prawn *Fenneropenaeus indicus* (formerly known as *P. indicus*) (Vijayan *et al.* 2003). In addition, environmental pollution can increase the susceptibility of prawns to disease and reduce reproductive output (Nash *et al.* 1988). These issues are poorly understood for western king prawn in South Australia.

1.4.3. Larval and juvenile stages

The life cycle of the western king prawn consists of two phases: 1) an offshore phase, where spawning of adults, and drift and growth of larvae occurs; and 2) an inshore phase, where settlement of post-larvae and growth through to the juvenile stage occurs (Figure 1.9).

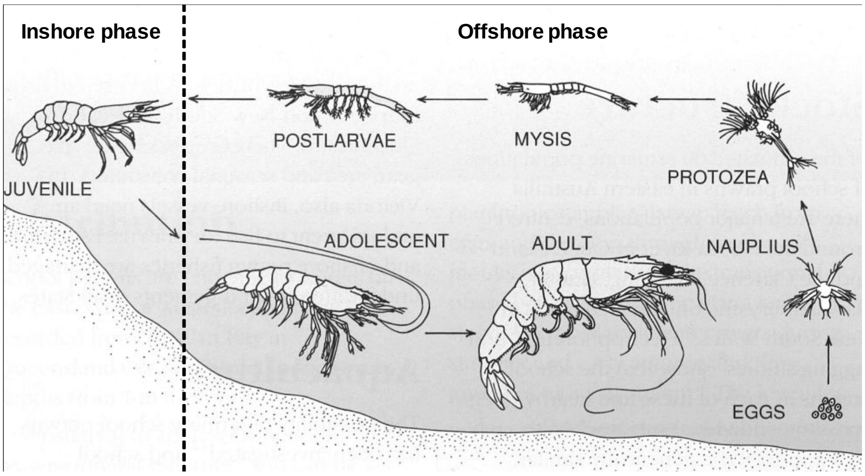
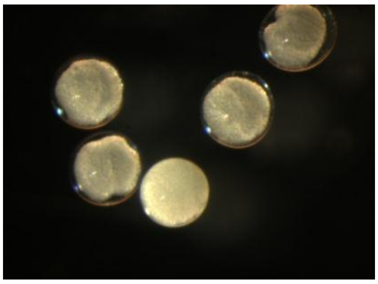


Figure 1.9. Life cycle of a penaeid prawn. Source: Kailola *et al.* (1993).

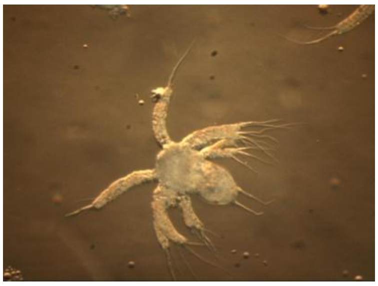
Following hatching of the egg, prawn larvae undergo four main stages of metamorphosis, i.e. nauplii, zoea, mysis and post-larvae (Figure 1.10). Approximate sizes of the early life stages are: eggs 300 µm (diameter), nauplii > 350 µm body length (BL), zoea > 0.9 mm BL, mysis > 2.0 mm BL and post-larvae > 6.0 mm BL (Shokita 1984; Roberts *et al.* 2012).

Temperature, salinity and food availability are generally considered to have the most influence on larval growth and survival in penaeid prawns (Preston 1985; Carrick 2003; Jackson and Burford 2003). Roberts *et al.* (2012) determined duration and survival of western king prawn larvae reared at different temperatures. An increase in temperature over a range of 17-25°C resulted in a shorter larval period (31.3 days at 17.1°C to 12.7 days at 24.4°C, Figure 1.11) and an increase in larval survival (36% at 17°C to 74% at 25°C), thus demonstrating the strong tropical affinity of this species.

Eggs



Nauplius sub-stage 1



Nauplius sub-stage 2

Nauplius sub-stage 3

Protozoea sub-stage 1

Protozoea sub-stage 2

Protozoea sub-stage 3

Mysis sub-stage 1

Mysis sub-stage 2

Mysis sub-stage 3

Post-larva

Figure 1.10. Development of the western king prawn early life stages (eggs to post-larvae).

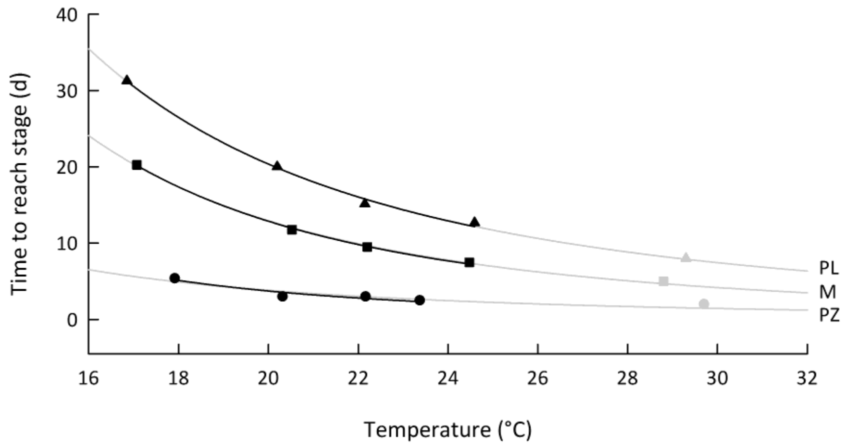


Figure 1.11. Effect of temperature on mean time (d) for western king prawns to reach zoea (Z), mysis (M) and post-larval (PL) stages from hatching. Black symbols and lines represent data from Roberts *et al.* (2012), while data in grey sourced from Shokita (1984). Figure reproduced from Roberts *et al.* (2012).

By incorporating mean SST data for Spencer Gulf into a seasonal developmental model, Roberts *et al.* (2012) predicted total larval duration to be shorter at the beginning of the spawning season (26.8 days from hatch date of 9 November) due to increasing daily water temperatures, compared to later in the season (35.4 days from 29 May) (Figure 1.12). Furthermore, larval duration was predicted to be significantly shorter in warmer northern waters (minimum 12.7 days) compared to southern waters (minimum 17.2 days) separated by latitude 34°S. These optimal temporal and spatial influences for larval duration and survival reflect the distribution of spawning females observed in November.

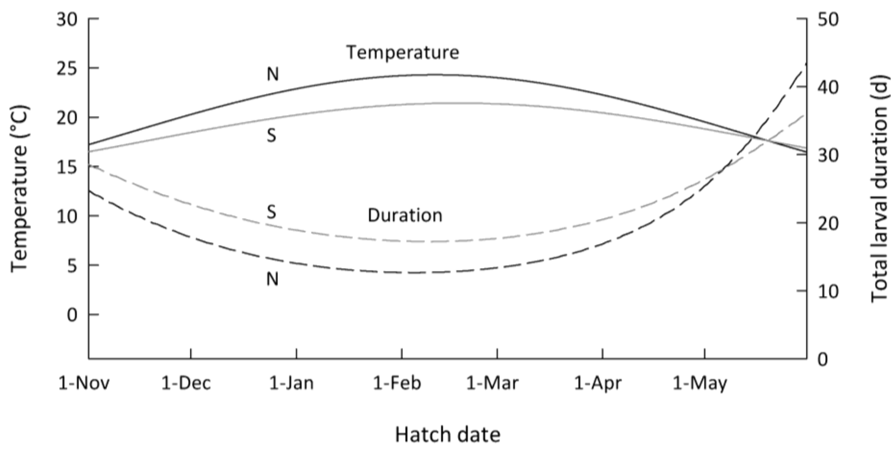


Figure 1.12. Predicted duration of western king prawn larval development (dashed lines) in northern (N, black) and southern (S, grey) Spencer Gulf waters at seasonal mean water temperatures (solid lines). Figure reproduced from Roberts *et al.* (2012).

Rodgers *et al.* (2013) examined the effect of temperature (range 17-25°C) on stage-specific size of western king prawn larvae, and showed that larval growth rate was dependent on temperature, with growth rate greater at higher temperatures. Despite this, larvae reared at 20°C reached the largest size, while those at either end of the experimental temperature range (17°C and 25°C) were smallest.

When considering monthly mean temperature in Spencer Gulf, the spawning time that would most likely maximise larval size in the Spencer Gulf is approximately November. This coincides with current management arrangements for the fishery that protect the spawning biomass at this time of year (i.e. fleet catch cap).

In marine invertebrate populations, larval dispersal, distribution and abundance are controlled by a combination of factors including reproductive dynamics of the adults, physiological tolerances, behaviour (i.e. vertical migration), and oceanographic processes such as wind-driven and tidal currents (Roberts *et al.* 2012). Bio-physical models that incorporate these parameters to predict larval dispersal and settlement provide potentially useful tools for fisheries management (Pedersen *et al.* 2003; Queiroga *et al.* 2007). Plankton sampling in Spencer Gulf has shown that western king prawn larvae are broadly distributed, with highest densities found north of Cowell (Carrick 1996). Larval densities varied significantly between years, probably due to differences in environmental conditions and spawning stock status.

Post-larvae settle in inshore nursery areas at 2-3 mm CL and can remain there for up to 10 months, depending on the time of settlement (Carrick 1996). The post-larvae produced from early in the spawning period, i.e. October/November, settle in nursery areas during December or January where they grow rapidly before emigrating to deeper water in May or June. Alternatively, post-larvae produced from spawning after January settle in nurseries from March, grow slowly, then 'over-winter' in the nursery areas before recruiting to the trawl grounds in February of the following year (Carrick 2003).

Mean natural mortality of juvenile western king prawn in Spencer Gulf nurseries during winter is estimated at 5% per week (Carrick 2003), while in Gulf St Vincent nurseries, over-wintering mortalities range from 0.2-16.5% (mean 7.9%) per week, with evidence of density-dependent mortality (Kangas 1999). These estimates of natural mortality for juvenile western king prawn are considerably lower than for other prawn species (Carrick 1996).

In Spencer Gulf, abundance of juvenile western king prawn is highest between February and May, with key nursery sites identified as False Bay, Fifth Creek, Mount Young, Port Pirie, and the Spit, all of which are in the north of the gulf (Carrick 1996; Roberts *et al.* 2005) (Figure 1.1). Two of these sites, False Bay and Port Pirie, were surveyed in May 2013 and April 2014, and have been chosen as the indicator sites for ongoing annual monitoring of juvenile abundance.

1.4.4. Stock structure

The stock structure of western king prawns in South Australia is uncertain. Analyses of rDNA by the South Australian Museum and SARDI (cited in Carrick 2003) have shown significant genetic differences in haplotype frequency between South Australian and Western Australian western king prawn samples. However, in an analysis of gene and genotype frequencies among South Australian populations using electrophoretic techniques, Richardson (1982) found no evidence of genetic isolation, suggesting a homogeneous stock. Notwithstanding the possibility that South Australia's prawn fisheries may comprise a single stock, they continue to be managed as three separate units based on historic arrangements.

1.4.5. Growth

Prawns undergo a series of moults to increase their size incrementally. The shedding of hard body parts during moulting means that the age of individuals cannot be reliably determined. The inability to determine the age of prawns has increased the reliance on tag-recapture or cohort analysis for the determination of growth parameters.

As part of the recent development of a bio-economic model for South Australia's prawn fisheries (Australian Seafood CRC Project No. 2011/750), tag-recapture data obtained for 2,027 female and 1,535 male prawns from Spencer Gulf from October 1984 to June 1991 (Carrick and Ostendorf 2005) were fitted to a seasonal von Bertalanffy growth model following the work of Xiao (1999; 2000; Xiao and McShane 2000b). Mean growth parameter values for male and female prawns are summarised in Table 1.6, and growth trajectories are shown in Figure 1.13.

Table 1.6. Seasonal von Bertalanffy growth parameters fitted to tag-recapture data for male and female western king prawns from Spencer Gulf.

Sex	L_{max}	K_0	A	t_ϕ
Males	45.9	0.00243	0.00331	69.0
Females	57.1	0.00217	0.00229	72.6

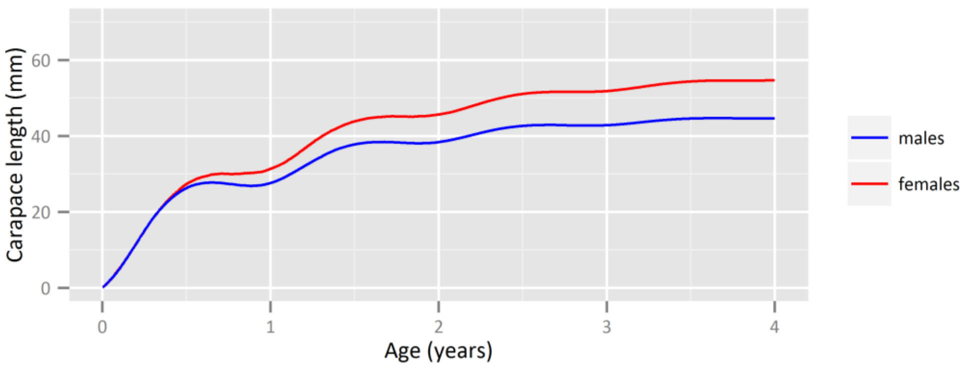


Figure 1.13. Seasonal von Bertalanffy growth trajectories for male and female western king prawns from Spencer Gulf with a birth date of 1 November.

The growth model for western king prawn in Spencer Gulf demonstrated strong seasonal growth. The derivation (from the growth model parameters) of growth rate K as a function of time predicted that growth rates for males and females reached their maxima in early March, and were slowest in early September (Figure 1.14). No growth was predicted to occur from late July to mid-October for males and from late August to late September for females. The growth model also indicated that females grow almost continuously in length throughout the year but at a slower rate in certain months than males.

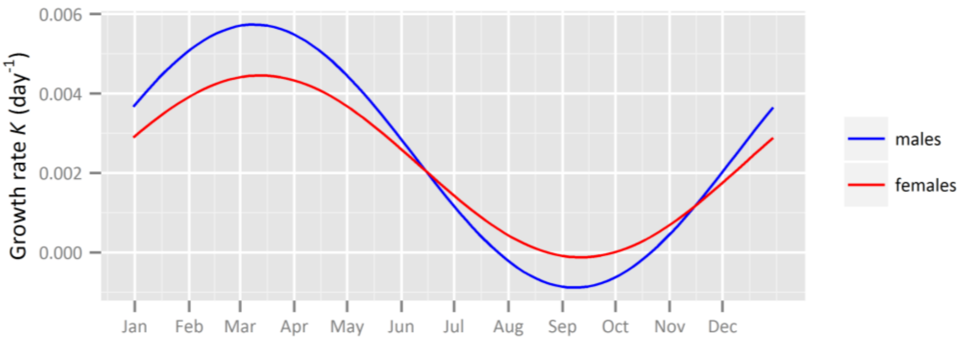


Figure 1.14. Seasonal growth rate of male and female western king prawns from Spencer Gulf.

1.4.6. Length-weight relationship

The relationship between carapace length (*CL*, mm) and weight (*W*, g) for the western king prawn from Spencer Gulf is described by the power function $W = 0.00124CL^{2.76}$ for males, and $W = 0.00175CL^{2.66}$ for females (Carrick 2003). The relationship for juveniles (where sex cannot be easily distinguished) from Gulf St Vincent is $W = 0.0066CL^{2.91}$ (Kangas 1999).

1.4.7. Movement

From the spatial analysis of the same tag-recapture data used to describe seasonal growth (Section 1.4.5), Carrick (2003) described three general movement patterns of the western king prawn in Spencer Gulf: 1) north to south movement in northern Spencer Gulf; 2) east to northeast movement from northern Cowell and the top of the Gutter; and 3) southeast movement from southern Cowell and the Gutter towards Corny Point (Figure 1.15). Carrick (2003) also noted that there was negligible movement for prawns tagged at Wallaroo, but this may have been attributed to the high level of fishing intensity in that region during the tagging study.

While the use of external tags (as used for prawns in South Australian studies) has been associated with higher mortality rates (Benzie *et al.* 1995) and suppressed growth rates (Penn 1975; Menz and Blake 1980) of prawns, particularly for small individuals, it is unclear whether they affect movement.

1.4.8. Natural mortality

Daily instantaneous rates of natural mortality for the western king prawn in Spencer Gulf range between 0.003 and 0.005 d^{-1} (King 1977). These estimates of natural mortality are comparable with Gulf St Vincent (at 0.003 d-1, or 0.102 mo-1, Kangas and Jackson 1997; Xiao and McShane 2000a) and Western Australian populations (0.002-0.005 d-1, Penn 1976), whereas estimates for prawns on the West Coast range more widely (0.001-0.014 d-1, Wallner 1985).

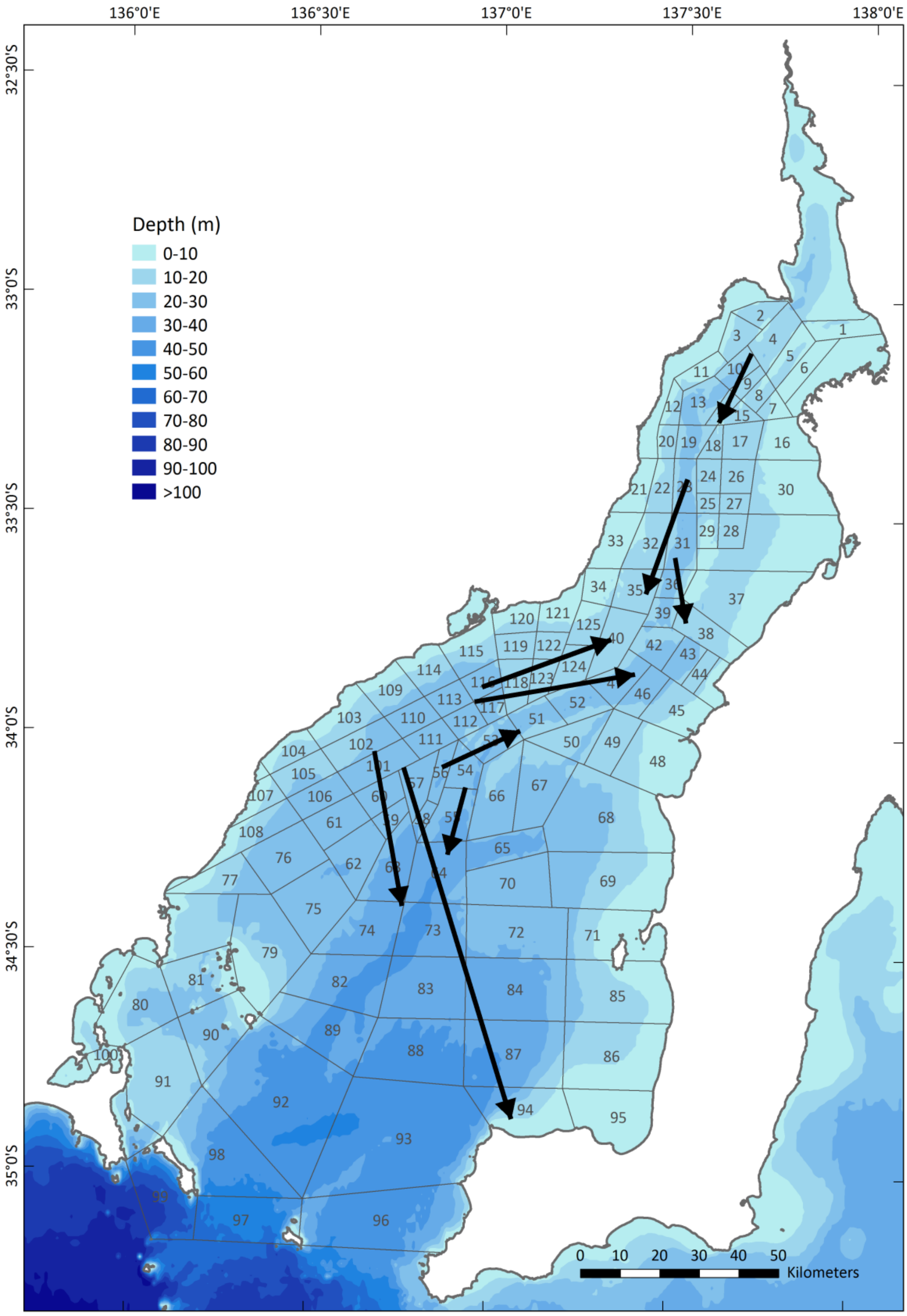


Figure 1.15. Generalised movement of western king prawn in Spencer Gulf determined from tag-recapture studies. Source: Carrick (2003).

1.4.9. Biosecurity and prawn health

Invasive species are a major threat to coastal ecosystems (Crooks and Soulé 1999). The most susceptible prawn habitat to invasive species is that of juvenile prawn nurseries. Some marine pests (e.g. the invasive alga *Caulerpa taxifolia*) can modify inshore environments in ways that may adversely impact prawn recruitment (Deveney *et al.* 2008). In recent surveys of key prawn nursery sites in Spencer Gulf and Gulf St Vincent, no marine pest species were observed (Roberts *et al.* 2010; SARDI, unpublished data).

Disease status and parasite loads are limiting factors in marine animal populations, although they are generally overlooked in fisheries management (Harvell *et al.* 2004). Climate change may increase the risks associated with spread of disease, and push species towards their physiological thresholds (Harvell *et al.* 2002; Vilchis *et al.* 2005; Pörtner and Knust 2007). Furthermore, environmental pollution from coastal industries can increase the susceptibility of aquatic animals to disease and reduce reproductive output (Nash *et al.* 1988).

Exotic (introduced) viral pathogens are considered one of the highest health risks for a prawn population due to their: 1) potential virulence; 2) rapid proliferation and infection; 3) general host non-specific nature; and 4) resistance and durability. These characteristics increase the chance of spreading, for example, by national and international movements of prawn (i.e. bait prawns) and other crustacean products. The ability for viral pathogens to survive the freezing process enabled one of the most virulent and financially-damaging penaeid viruses, White Spot Syndrome Virus (WSSV), to spread from Asia into the USA (Lightner *et al.* 1997).

Focusing on viruses, Roberts *et al*. (2010) assessed the disease status of prawns collected from key nursery sites in Spencer Gulf and Gulf St Vincent. Although an endemic, and likely harmless, Monodonbaculovirus (MBV)-like virus was observed in ~60% of prawns (MBV is a common virus known to occur throughout Australia), it was concluded that juvenile prawn populations in South Australia are free of the disease-causing (and notifiable) viruses found in Australia and overseas, including Infectious Hypodermal and Haematopoietic Necrosis Virus (IHHNV), WSSV, Hepatopancreatic Parvovirus (HPV) and Gill-Associated Virus (GAV). Nevertheless, the introduction of viruses through imported prawn and crustacean products remains a high risk, and regular monitoring of prawn nurseries is necessary to enable early detection and response.

Common pollutants in South Australian marine waters include heavy metals, high nutrient loads from coastal industries, and petroleum discharges (Edyvane 1999). In Spencer Gulf, juvenile prawn habitat appears to have been influenced by oil spills (Roberts *et al.* 2005) and industrial effluent (Carrick 2003), while in Gulf St Vincent, there is anecdotal evidence that juvenile prawn abundance at Barker Inlet has significantly declined since the early 1970s, possibly due to anthropogenic factors such as increased nutrient loading (Kangas 1999). Although these sources of pollution are common, little research has been conducted to examine their impact on prawn nursery habitat.

1.5. Previous fishery assessments

The first stock assessment for the SGPF was completed in 1998 (Carrick and McShane 1998). Subsequent stock assessments in 2000 and 2001 were the first to consider the biological PIs of the fishery (Carrick and Williams 2000; 2001). The 2003 stock assessment report (Carrick 2003) represented a considerable advance on previous assessments as it included a description of the life history of prawns and management of the fishery, detailed spatial and temporal analyses of fishery-dependent and fishery-independent data, assessment of the fishery against the PIs defined in the first management plan (MacDonald 1998), and a review of the biology of the western king prawn. Subsequent assessments (Dixon *et al.* 2005; 2007; Dixon and Hooper 2008; Dixon *et al.* 2009; 2010; 2012; 2013; Noell *et al.* 2014) have evolved further to include, in addition to Carrick (2003), detailed spatial and temporal analyses of survey results and fishing activities, standardisation of survey CPUE, development of an egg production model, and information on the extent and status of suitable juvenile habitats.

Comprehensive annual stock assessment reports over the last decade have not only informed decisions on the biological sustainability of the resource, but also provided a strong basis for further research into the biological and economic aspects of the fishery.

1.6. Stock assessment program

The 2013/14 stock assessment program for the SGPF conducted by SARDI Aquatic Sciences comprised five components. These were to: 1) manage the daily logbook program and collate and analyse commercial catch and effort data; 2) conduct fishery-independent stock assessment surveys prior to, during and toward the end of the fishing year to inform fishing strategy decisions and assess the fishery against the PIs in the 2007 Plan (although these have now become superseded by the PIs in the 2014 Plan); 3) report on the by-catch survey conducted in February 2013; 4) monitor abundance of juvenile prawns and biosecurity issues at key nursery sites; and 5) produce an annual stock assessment report for the fishery.

1.7. Information sources used for assessment

1.7.1. Stock assessment surveys

Stock assessment surveys are conducted three times per fishing year, i.e. November, February and April, using industry vessels, skippers and crews, with independent observers placed on each vessel, to collect data on prawn size and catch rates. Under the 2007 Plan, these data serve two important purposes: 1) determine the mean catch rate for prawns larger than 20+ grade in the November survey, and mean total and 20+ grade catch rates in February and April surveys as measures of targeted biomass, current biomass and future biomass, respectively; and 2) inform the development of fishing strategies according to harvest decision rules. Additionally, data from the November survey provides information on egg production, and data from the February survey provides information on recruitment. Survey data are used for the same purposes in the 2014 Plan, except for February and April surveys, where the mean catch rate for prawns larger than 20+ grade (‘adult’ prawns) is primarily used to develop fishing strategies as it is more indicative of the targeted biomass than total catch rate.

The current survey design was adopted in November 2004 to ensure consistent spatial and temporal replication of survey shots, and thereby improve the robustness of surveys as a measure of relative biomass. There are a total of 209 shot locations that have been used for stock assessment surveys (Figure 1.16). While all shot locations provide a comprehensive coverage of the gulf, a subset of these (183 for November survey, 185 for February survey, and 161 for April survey) have actually been used since implementation of the 2007 Plan (Dixon and Sloan 2007) to determine the fishing strategy following each survey. For the remainder of this report, the 209 shot locations and its subsets are referred to as 'Management Plan shots' and 'stock assessment shots', respectively.

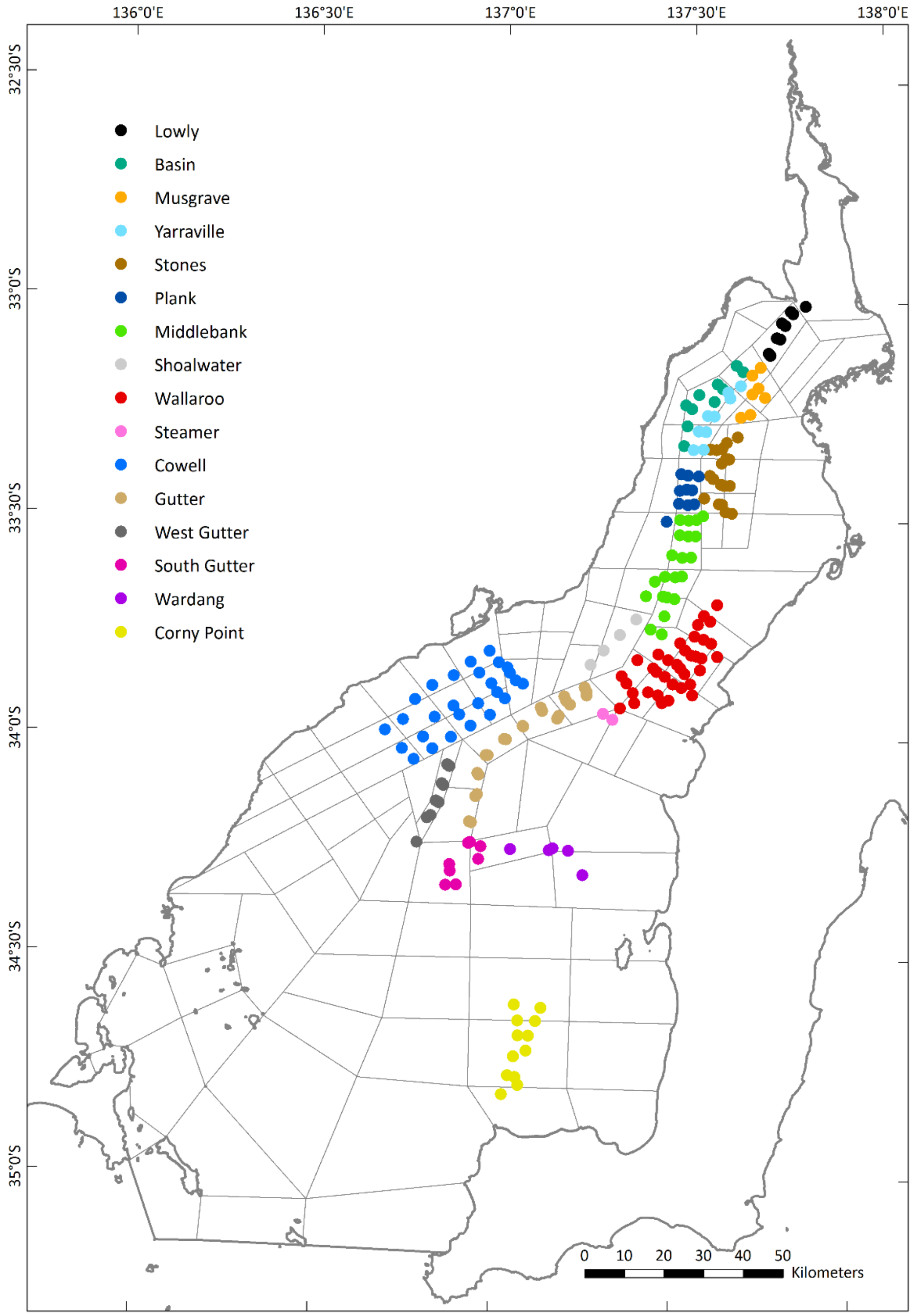


Figure 1.16. The 209 stock assessment survey shot locations for the Spencer Gulf Prawn Fishery.

1.7.2. Commercial logbook data

Licence holders are required to complete and submit a daily catch and effort logbook to SARDI at the end of each month. A monthly unloading logbook is also completed to enable validation and adjustment of daily catch estimates.

Since the reporting of commercial catch and effort began in 1968, there have been a number of modifications to improve the information available for assessment. From July 1987, the previously used regular grid for reporting catch and effort was replaced with 125 irregularly-shaped polygons, or fishing blocks (Figure 1.1), ranging from 29 km^2 (Block 58) to 1,029 km^2 (Block 93) (mean: 166 km^2) to better reflect the fishing grounds and differences in prawn size and abundance (Carrick 2003). Recent changes to the daily logbook include the requirement for licence holders to record exact location (GPS coordinates) for at least three trawl shots per night, size-grade data of the prawn catch, and retained by-product (southern calamari, *Sepioteuthis australis*, and slipper lobster, *Ibacus* spp.).

2. METHODS

2.1. Stock assessment surveys

2.1.1. Data collection

Eight to ten commercial vessels from the SGPF, with an observer onboard each vessel, were required to complete each survey in 2013/14. Surveys were conducted on 2-3 November 2012, 28 February-1 March 2014 and 27-28 April 2014. As with previous surveys, these dates were chosen to correspond with the dark moon (surveys are usually conducted over two nights, i.e. the night before and night of the dark moon). At each shot location, the survey vessel trawled along a pre-determined path (with the aid of a marine chart plotter) for 30 min. The distance trawled at each location depends on trawl speed (3-5 knots), which is influenced by vessel power, tide and weather conditions.

Data collected for each shot location included total catch, catch of 20+ grade prawns, number of nets used, trawl duration, tide direction, and number of prawns in a 7 kg bucket[3] as a rapid measure of prawn size. A random sample of 100 prawns was also taken from each shot to obtain information on sex ratio and length frequency, which were used to calculate measures of egg production and recruitment.

2.1.2. Egg production

Annual egg production of western king prawns in Spencer Gulf was estimated using an egg production model, which has been used since 2004/05. Model calculations are based on biological data collected from the Management Plan shot locations surveyed in November, and rely on several assumptions: 1) catchability of prawns is constant during the survey; 2) female prawns spawn three times during the spawning period; 3) spawning frequency does not vary with prawn size; 4) natural

[3] The number of prawns per 7 kg is referred to in the industry as a ‘bucket count.’

mortality is zero; 5) percentage of females within each grade does not vary during the spawning period; and 6) sex-specific length frequency data from surveys are representative of the population.

The following calculations describe the application of the egg production model:

1. Mean weight of prawns for each prawn grade was obtained from commercial processors;
2. Mean size (mm, CL) of female prawns for each grade was derived from 1 using the length-weight relationship for females;
3. Catch rate per grade was calculated (in kg h^{-1}, adjusted for two nets);
4. Catch rate of females per grade per hour was derived from 3 and the mean proportion of females in the corresponding grade;
5. Number of females per grade per hour was derived from 1 and 4;
6. Number of mature females per grade per hour was derived from 2 and 5, and the proportion of mature females for each grade using the logistic equation provided by Carrick (1996);
7. Number of fertilised eggs produced per grade per hour was derived from 2, the size-fecundity relationship for prawns from Gulf St Vincent (M. Kangas unpublished, cited in Carrick 2003), and the proportion of eggs that are successfully fertilised per grade (derived from findings of Courtney and Dredge 1988);
8. Number of fertilised eggs produced per hour was calculated as the sum of data from 7 across all grades; and
9. Total number of fertilised eggs produced per hour was calculated by multiplying the data from 8 by the assumed spawning frequency (three times per spawning period), and summing their products over all shots.

The final calculation of the model (step 9), is interpreted as the potential number of fertilised eggs per hour that females could have contributed to egg production throughout the spawning period.

2.1.3. Recruitment

The recruitment index developed by Carrick (2003) was calculated as the square root of the number of recruits per nautical mile trawled from 39 shot locations in the north of the gulf during February surveys. ‘Recruits’ are defined for this purpose as prawns <33 mm CL for males and <35 mm CL for females. The recruitment index has been calculated for most February surveys conducted since 1982.

The mean number of recruits per trawl-hour was also determined for each survey period from 2004/05 to 2013/14 to identify temporal (inter and intra-annual) trends in relative abundance of recruits throughout the gulf. The 2013/14 abundance estimates were broken down further by region and compared with corresponding means for the previous nine years to examine the spatial distribution of recruits.

2.2. Commercial logbook data

2.2.1. Catch, effort and CPUE

Catch and effort data were obtained from two sources: 1) annual (1968–1973) and monthly data (January 1973–June 1988) from South Australian Fishing Industry Council (SAFIC) annual reports; and 2) daily and monthly data (July 1988–June 2014) from catch and effort logbooks. Estimated prawn catch for each shot was adjusted using validated catches reported in monthly logbooks.

Catch and effort data are presented temporally (fishing year and month) and spatially (region, as defined in Figure 1.1). Catch is also presented for the early spawning period (October to December) compared to all other fishing months. Commercial CPUE was calculated by dividing (adjusted) catch by effort, and expressed in kg h^{-1} or lb min^{-1}.

2.2.2. Prawn size

Information on prawn size was obtained from commercial grade data for fishing years 1978/79, 1998/99 and 2002/03–2013/14. Prawn grade data were used to examine annual trends in the size of commercially harvested prawns and determine the mean nightly prawn size.

Prawn grades generally refer to the number of prawns per pound (e.g. 'U10' means fewer than 10 prawns per pound). Since 2002/03, up to 23 grade categories have been used to describe the size of prawns in the commercial catch due to different marketing practices in the industry. To ensure consistent interpretation of prawn size, grades were converted to four grade categories, U10 (extra large, XL), 10/15 (large, L), 16/20 (medium, M), and 20+ (small, S) (Table 2.1). For analysis of trends within years, a fifth category, soft and broken (S&B), was established for prawns that were not graded. The number of prawns per kilogram for each of the 23 prawn grades was estimated from the prawn grade category (e.g. grade category 10/15 was estimated at 12.5 prawns per pound or 193.9 prawns per 7 kg) (Table 2.1).

The mean nightly prawn size $\overline{pp7kg_N}$ for the fleet was calculated from the catch by grade data provided in commercial logbooks and the number of prawns per kg for each grade using the equation:

$$\overline{pp7kg_N} = \frac{\sum_{v=1}^{39}\left[\sum_{g=1}^{23}\left(C_{v,g} \times pp7kg_{v,g}\right)\right]}{\sum_{v=1}^{39}\left[\sum_{g=1}^{23}\left(C_{v,g}\right)\right]},$$

where $C_{v,g}$ and $pp7kg_{v,g}$ are the catch and number of prawns per 7 kg, respectively, for vessel v and grade g.

Mean annual prawn size $\overline{pp7kg_Y}$ was calculated using the equation:

$$\overline{pp7kg_Y} = \frac{\sum_{N=1}^{k}\left(C_N \times \overline{pp7kg_N}\right)}{\sum_{N=1}^{k}\left(C_N\right)},$$

where C_N is the total catch by the fleet on night N (of a fishing year that comprises k nights).

Table 2.1. Conversion of prawn size grades reported in commercial logbooks to broader categories for analysis. Also shown for each grade is the estimated median number of prawns per 7 kg (pp7kg).

Prawn grade category	Grades reported in logbook	pp7kg
U10 (XL)	U6	92
	XL	100
	U8	108
	U10, L	139
10/15 (L)	9/12	162
	U12	169
	LM, 10/15	193
	13/15	216
	10/20 (50%), 12/18 (50%)	231
16/20 (M)	10/20 (50%), 12/18 (50%)	231
	M, 16/20	277
20+ (S)	SM, 19/25	339
	21/25	354
	S, 20+, 21/30	393
	26+	431
	30+, 31/40	547
	41/50	630
Soft and broken	S&B, B&D, MIX, REJ, SMS, ERR, *(blank)*	-

Although target size criteria for fishing (as defined in the 2007 Plan) vary according to the time of the year and fishing strategy adopted, the proportion of nights where the mean size of prawns caught are smaller than a specified size is useful for monitoring inter-annual variability of the size of prawns caught by the fleet. Thus, data are presented on the number and percentage of vessel-nights of the fishing year when prawns were smaller than the bucket counts of 220, 250 and 280 pp7kg.

2.3. Catch standardisation

Catch rates obtained from stock assessment surveys or fishing are assumed to be proportional to prawn abundance. However, before catch rates can be used as an index of relative biomass, it is important to standardise catch to remove the influence of variables that are not related to abundance.

Analyses were conducted on survey data obtained from the Management Plan shot locations from 2004/05–2013/14 and daily logbook data from 1990/91–2013/14, aggregated to catch (survey: kg trawl-shot^{-1}; fishery: kg block-vessel-night^{-1}). Survey catches (per 30-min trawl-shot) were adjusted to two nets where necessary. The logbook database prior to 1991 was incomplete, particularly by block and vessel, and therefore not included in the standardisation.

Generalised linear modelling (GLM; Nelder and Wedderburn 1972) is the most common method for standardising catch and effort data from fisheries (Maunder and Punt 2004), and was employed for the standardisation of catches. All analyses were performed using the R programming language (R Core Team 2013). Box-Cox transformation (Box and Cox 1964) and diagnostic plots indicated that, among different distributional assumptions tested, a Gaussian error distribution and identity link fitted to cube root transformed catches were appropriate for survey and fishery data. The analyses included fixed terms (Xβ), and followed the terminology and notation of O'Neill *et al.* (2014). Where data (X_1, X_2, …X_{10}) were relevant and available, the models were fitted to estimate the following parameter effects:

- Scalar model intercept β_0;
- Abundance β_1 for data X_1 (fishing year-survey/month combined factor);
- Region β_2 for data X_2 (amalgamation of fishing blocks; 10 regions) (Figure 1.1);
- Vessel β_3 for data X_3 (identified by licence number; 39 licences);
- Tide direction β_4 for data X_4 ('against', 'slack' or 'with'; relative to the towing direction);
- Tide strength β_5 for data X_5 (m h^{-1}; sum of the absolute differences between consecutive high and low water marks at Whyalla over a ~24 h period (from noon) divided by the actual hours elapsed; survey only) (BOM 2014b);
- Sea surface temperature β_6 for data X_6 (daily mean near the middle of the gulf at 33.88°S, 137.38°E, derived from satellite data, smoothed with moving average of 7 days to keep daily variation generally within ± 0.2°C) (NASA 2014);
- Lunar phase β_7 for data X_7 (fraction of moon illuminated at midnight AEST) (USNO 2014);
- Lunar phase (lagged) β_8 for data X_8 (lunar phase shifted ¼ phase; only considered when the primary variable β_7 was significant);
- Cloud cover β_9 for data X_9 (mean fraction from three-hourly readings, measured in eighths, between 1800 and 0600 hours) (BOM 2014a); and
- Fishing effort β_{10} for data X_{10} (hours).

The most parsimonious model for survey and fishery catches (Table 2.2) was obtained using a stepwise removal procedure; firstly, by determining the generalised variance inflation factor (GVIF; Fox and Monette 1992) and removing terms causing collinearity (as indicated by $\mathrm{GVIF}^{1/(2df)}$ values > 2), and secondly, by removing non-significant terms in analysis of deviance (type II method; PIRSA 2014) according to the *F*-statistic.

Table 2.2. Final GLMs used to standardise survey (2004/05–2013/14) and fishery (1990/91–2013/14) CPUE.

Survey	
Response:	$\sqrt[3]{\text{kg trawl-shot}^{-1}}$
Fixed terms:	$\beta_0 + X_1\beta_1 + X_2\beta_2 + X_3\beta_3 + X_4\beta_4 + X_7\beta_7$
Offset	β_{10}
Predictions:	β_1
Fishery	
Response:	$\sqrt[3]{\text{kg block-vessel-night}^{-1}}$
Fixed terms:	$\beta_0 + X_1\beta_1 + X_2\beta_2 + X_3\beta_3 + X_7\beta_7 + X_8\beta_8 + X_{10}\beta_{10}$
Offset	—
Predictions:	β_1

The 'effects' package in R was used to determine predicted means for the main effects of the model (e.g. year-survey/month) by setting other numeric variables to their mean values (except fishing effort, which was specified), and by setting factors to their proportional distribution in the data by averaging over contrasts (Fox 2003; Fox and Hong 2009). Survey effort was virtually constant (mean 0.48 h) and therefore treated as an offset term, whereas fishing effort had a multimodal distribution, so the mean of the largest two modes (9.33 h) (as determined by the R package 'mixdist', Macdonald and Du 2012) was used to represent typical effort per block per vessel-night in the fleet. As the predicted means were on the transformed scale, the cubic-root bias correction $\mu^3 + 3\mu\sigma^2$ was required to back-transform to their original scale (Kendall *et al.* 1983), where μ is the predicted mean on the transformed scale, and σ^2 is the model variance. Predicted mean catch was expressed in kg h^{-1} and lb min^{-1} for industry reporting needs.

2.4. Other research

2.4.1. Juvenile prawn survey

The juvenile prawn survey program has been conducted on an irregular basis in the upper region of Spencer Gulf since 1992. The objectives of the program are to: 1) determine and monitor annual changes in relative abundance of juvenile western king prawns at key locations; 2) collect and preserve juvenile prawn samples for future reference and potential testing of diseases and viruses; and 3) maintain a chain of custody of the samples and information collected.

Two sites, False Bay and Port Pirie (Figure 1.1), were recently chosen as indicator sites for ongoing annual monitoring of juvenile abundance. Both sites were surveyed in April 2014 using the 'jet net method', which comprises a small beam trawl (mouth dimensions: 0.9 m wide × 0.3 m high) fitted with fine mesh (2 mm square nylon) and water jets, and is used to penetrate the sand-mud substrate and suspend the prawns for collection (Roberts *et al.* 2005). At each site, four replicate tows of 100 m in length were conducted. Each tow covered an area of 90 m^2. Relative abundance was expressed as number of juveniles m^{-2}.

2.4.2. Tagging study

A prawn tagging study was carried out onboard a commercial trawler in the southern regions of Spencer Gulf at the end of the 2011/12 and 2012/13 fishing years. The objective of the study was to determine whether prawns in these regions were most likely to remain within the gulf or move out of the gulf.

In June 2012, ~2,000 prawns were caught, measured, tagged and released in South Gutter (Figure 1.1). One year later, in June 2013, an additional ~4,000 prawns were caught, measured, tagged and released in Corny Point, South Gutter and Thistle regions (Figure 1.1). If any tagged prawns were recaptured in subsequent surveys or fishing, the fleet were requested to place these prawns in a freezer along with a label containing details on vessel, tag number, date and GPS coordinates. The Executive Officer representing the Spencer Gulf and West Coast Prawn Fishermen's Association (SGWCPFA) coordinated the collection and delivery of recaptured prawns to SARDI for analysis.

2.5. Fishery performance

Performance of the fishery for the 2013/14 fishing year was assessed against the LRPs for the following key biological PIs in the 2014 Plan (PIRSA 2014):

1. Weighted mean catch rate of adult prawns from the three stock assessment surveys;
2. Recruitment index from the February stock assessment survey (method described in Section 2.1.3);
3. Mean egg production from the November stock assessment survey (Section 2.1.2);
4. Mean commercial CPUE (Section 2.2.1);
5. Return of commercial daily logbooks for all licences and all nights fished;
6. Update of the strategic research plan; and
7. Completion of all three stock assessment surveys.

2.6. Fishing strategy assessment

Immediately after each survey, mean catch rates from stock assessment shot locations were calculated to determine the catch cap for the fleet (November survey) or the nature of the fishing strategy (February and April surveys; Table 2.3 and Figure 2.1), and associated criteria (minimum prawn size and nightly catch) according to decision rules in the Plan (Dixon and Sloan 2007) (Table 2.4). This is to ensure that fishing strategies are developed in a timely manner so that the fleet is able to commence fishing the next night.

Table 2.3. Lower and upper catch rate thresholds for determining the nature of fishing strategy following February and April surveys.

Measure	Survey	Lower	Upper
Mean 20+ grade catch rate	November	0.4	
	February	1.8	-
	April	1.5	-
Mean total catch rate	November	3.5	4.9
	February	4.4	5.9
	April	5.9	8.1

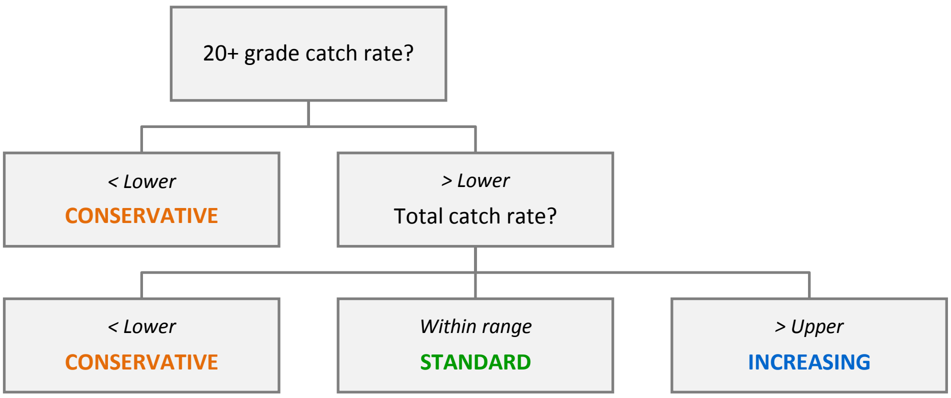


Figure 2.1. Decision tree used to determine the nature of the fishing strategy following stock assessment surveys. Figure reproduced from Dixon and Sloan (2007).

Table 2.4. At-sea decision rules for the Spencer Gulf Prawn Fishery. Abbreviations: Cons., conservative; Std, standard; Incr., increasing; NA, not applicable.

Fishing period	Nov & Dec	Mar & Apr			May & Jun		
Nature of strategy	Survey catch rate – catch cap relationship	Cons.	Std	Incr.	Cons.	Std	Incr.
Catch cap	Variable, up to 600 t		NA			NA	
Target prawn size (pp7kg)	≤250	≤200	≤220	≤240	≤220	≤240	≤260
Min. nightly catch per vessel	350 kg		400 kg			400 kg	

As survey results are calculated within only a few hours after the survey, there is limited time to verify the accuracy of the electronic logbook data provided by the skippers. An extensive quality assurance process (see Section 2.7 below) was followed to validate the survey data some months after their completion. Unvalidated and validated survey results are presented in this report and compared to determine whether there would have been any implications to the actual fishing strategy applied.

Effectiveness of the real-time management by the CAS of the 2013/14 fishing strategies was evaluated by comparison of the mean prawn size (by fishing period and fishing block) and mean nightly catch across the fleet (by fishing period) with the nature of the fishing strategy and associated criteria. Detailed maps for each survey and fishing period throughout 2013/14 are provided in Appendix A.

2.7. Quality assurance of data

2.7.1. Research planning

The 2013/14 research requirements of PIRSA Fisheries and Aquaculture for the SGPF were discussed at various times with fisheries managers and industry representatives throughout the preceding 12 months and subsequently presented as a research scope to confirm their understanding of proposed research and deliverables. This ensured that the proposed research was consistent with the needs of PIRSA Fisheries and Aquaculture to meet the obligations in the *Fisheries Management Act 2007.*

2.7.2. Data collection

Commercial fishers are advised on the procedures and requirements for conducting surveys and completion of the required fishing logbook on a regular basis, usually at the commencement of each fishing season. The data provided by commercial fishers were checked by SARDI prior to acceptance and potential errors corrected through direct correspondence with individual commercial fishers. Independent observers are trained to record survey data using methods described in stock assessment reports for the SGPF and by following standard operating procedures in an observer handbook that is updated annually.

2.7.3. Data entry, validation, storage and security

All logbook data were entered and validated according to the quality assurance protocols identified for the SGPF in the SARDI Information Systems Quality Assurance and Data Integrity Report (Vainickis 2010). Data were stored in an Oracle database, backed up daily, with access restricted to SARDI Information Systems staff. Extracts from the database were provided to SARDI prawn researchers on request. All fishery-independent data were entered into another Oracle database. Accuracy of survey data entry was verified by: 1) performing a series of checks for any inconsistencies or errors in the data file; and 2) checking a subset of the data (20%) against the original data sheets, including any errors that could not be resolved from examining the file alone. Once validated, data were uploaded and stored on a network drive with restricted access to SARDI staff involved in research projects in the Inshore Crustaceans Subprogram.

2.7.4. Data and statistical analyses

Data were extracted from the databases using established protocols. Accuracy of the data extracted was checked by comparing pivot table summaries with previous data extractions. Accuracy of data analyses was achieved in two ways. First, data analysis was carried out for multiple years at a time (where possible) to reproduce the same results of previous years. Second, data analyses were independently undertaken by two SARDI researchers and results subsequently compared. If either method yielded any discrepancies in the data or the results, the two SARDI researchers reviewed each other's analyses to resolve the discrepancy.

2.7.5. Data interpretation and report writing

The results, their interpretation and conclusions provided in the report were discussed with peers, PIRSA Fisheries and Aquaculture and industry representatives (including some licence holders). All co-authors reviewed the report prior to the report being formally reviewed by two independent scientists at SARDI in accordance with the SARDI report review process. External review of the report was done by the Prawn Fisheries Manager at PIRSA Fisheries and Aquaculture.

3. RESULTS

3.1. Stock assessment surveys

3.1.1. Nominal survey catch rate

An increase in mean total catch rate and mean 20+ grade catch rate was observed in all three stock assessment surveys in 2013/14 compared to 2012/13 (Figure 3.1). Despite these increases, both catch rate measures for the February survey (total: 4.33 lb min^{-1}; 20+ grade: 1.53 lb min^{-1}) remained below lower thresholds of the 2007 Plan (4.40 lb min^{-1} and 1.80 lb min^{-1}, respectively). All other mean survey catch rates were within historic levels (as indicated by the upper and lower thresholds).

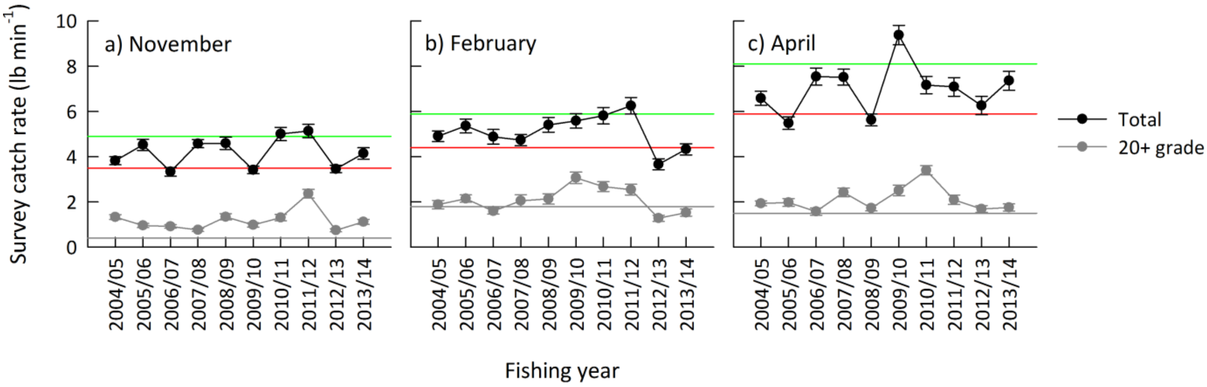


Figure 3.1. Mean (± 1 SE) total and 20+ grade catch rates in a) November, b) February, and c) April surveys from 2004/05–2013/14. Red and green reference lines indicate lower and upper threshold total catch rates, respectively, and the grey reference line indicates the lower threshold for 20+ grade catch rate.

3.1.2. Egg production

Mean egg production per hour trawled during the November 2013 survey (806 ± 48 million eggs trawl-hour^{-1}) was 25% higher than November 2012 (643 ± 36 million eggs trawl-hour^{-1}), 45% above the annual mean for the previous nine years (November 2004–2012: 556 million eggs trawl-hour^{-1}), and the highest estimate for November surveys since 2004 when egg production was first estimated (Figure 3.2).

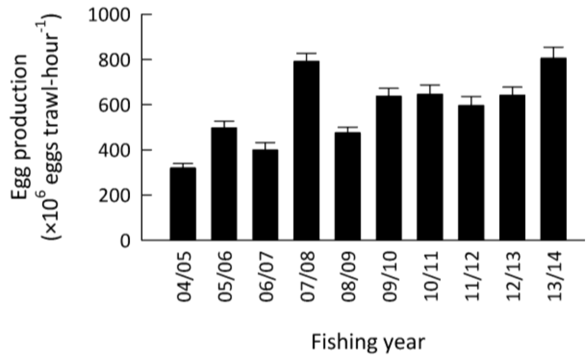


Figure 3.2. Mean (± 1 SE) egg production during November surveys from 2004/05–2013/14.

3.1.3. Recruitment

A mean recruitment index ($\sqrt{\text{recruits nm}^{-1}}$) of 43.3, calculated from length-frequency data obtained from the February 2014 survey, was above the limit reference point (LRP = 35) (Figure 3.3). As the index is square-root transformed, a two-fold increase in the index translates to a four-fold increase in the number of recruits per nautical mile. In the back-transformed scale, the February 2014 recruitment index represents a 61% increase in recruits from the previous year (February 2013: 34.1) and is 5% higher than the historic mean (February 1982–2013: 42.2).

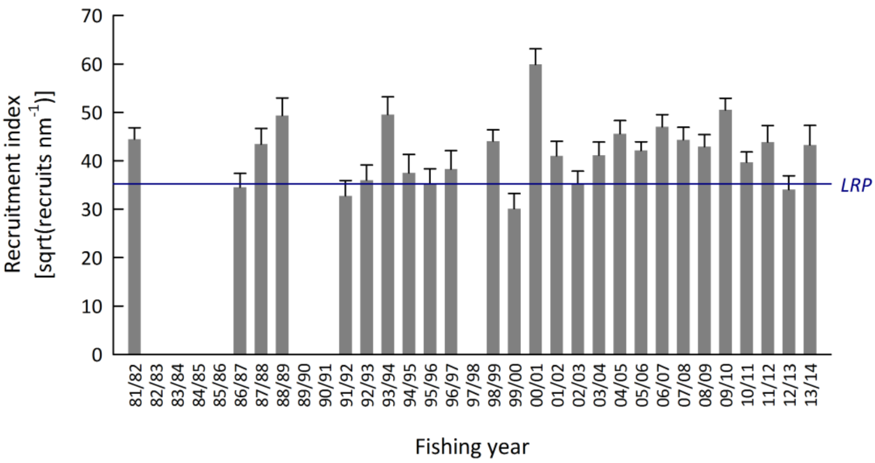


Figure 3.3. Mean (± 1 SE) recruitment index for 39 shot locations in upper Spencer Gulf surveyed in February from 1981/82–2013/14. The limit reference point (LRP) is 35.

Of the three stock assessment surveys since 2004/05, February surveys yielded the highest relative abundance of recruits across all Management Plan shot locations, except 2007/08, 2010/11 and 2012/13 when recruitment was highest in April (Figure 3.4). While the mean abundance (± SE) in February 2014 (2,020 ± 104 recruits trawl-hour^{-1}) increased by 33% from the previous year (1,515 ± 175 recruits trawl-hour^{-1}), numbers in April 2014 (1,514 ± 217 recruits.trawl-hour^{-1}) were 30% less than the year before (2,159 ± 225 recruits trawl-hour^{-1}). The abundance of recruits in 2013/14 were 17%, 53% and 41% below the annual means for November, February and April surveys, respectively, over the previous nine years (2004/05–2012/13: 1,085, 3,071 and 2,582 recruits trawl-hour^{-1}).

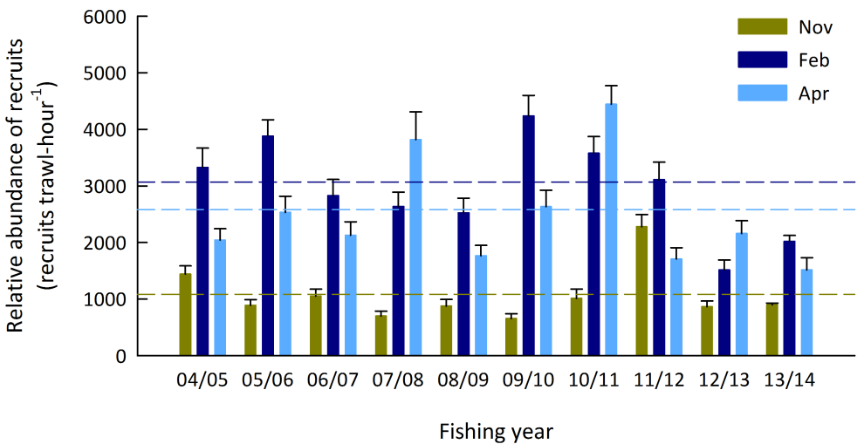


Figure 3.4. Mean (± 1 SE) relative abundance of recruits throughout Spencer Gulf during November, February and April surveys from 2004/05–2013/14. Dashed lines represent the previous nine-year annual mean for November, February and April surveys (2004/05–2012/13).

Regional assessment of recruits indicated that mean annual recruitment for the nine-year period 2004/05–2012/13 was highest in the North across all three surveys, but also relatively high in the Gutter in November, Middlebank/Shoalwater in February, and West Gutter and Gutter regions in April (Figure 3.5). Notable differences in 2013/14 to the long-term average distributions were fewer recruits in the North across all three surveys, highest numbers in West Gutter and Cowell in November, and substantially lower numbers in Middlebank/Shoalwater in February. While only relatively few recruits appear in the Wardang and Corny Point regions throughout the fishing year; low numbers were also observed in Middlebank/Shoalwater and Wallaroo in November 2013 and February 2014, and in Wallaroo in April 2014.

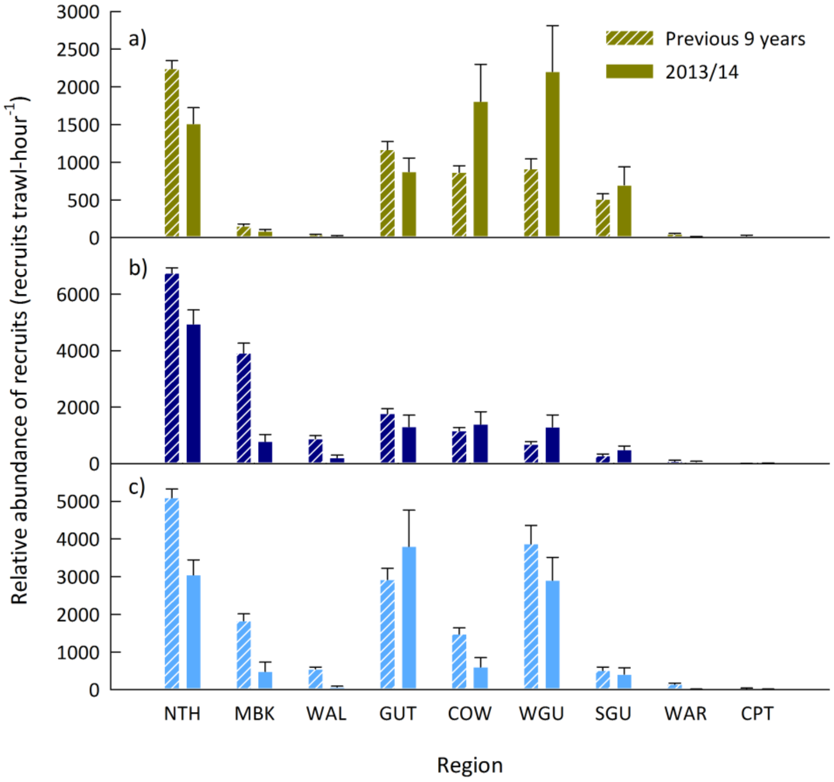


Figure 3.5. Comparison of mean (± 1 SE) relative abundance of recruits in each region during a) November, b) February and c) April surveys in 2013/14 (solid bars) with the previous nine years (2004/05–2012/13, hatched bars). See Figure 1.1 for abbreviations of regions.

3.2. Catch and effort statistics

3.2.1. Annual trends

The total harvest of 1,675 t for the 2013/14 fishing year is within the historical range and at the 22nd percentile since 1973/74 (range: 1,048-2,512 t; mean: 1,912 t ± 47 t) (Figure 3.6). However, it is marginally (1%) less than 2012/13 (1,699 t) and the equal smallest harvest (with 2011/12) since 2002/03 (1,479 t).

Annual total effort increased rapidly from 6,795 h in 1968 to 45,786 h in 1978/79 (Figure 3.6). Since the peak of 1978/79, there appears to be two general trends in effort. Firstly, effort declined steadily and significantly over a 27-year period up to and including 2004/05 (linear regression, LR: R^2 = 0.91, p < 0.001) at a mean rate of -937 h per year. Secondly, during the nine years since 2005/06, annual effort has fluctuated around a mean (and SD) of 18,179 ± 974 h. Effort for the 2013/14 fishing year was 19,901 h, which represents 43% of the historic peak in 1978/79 and a 5% increase from 2012/13 (19,008 h).

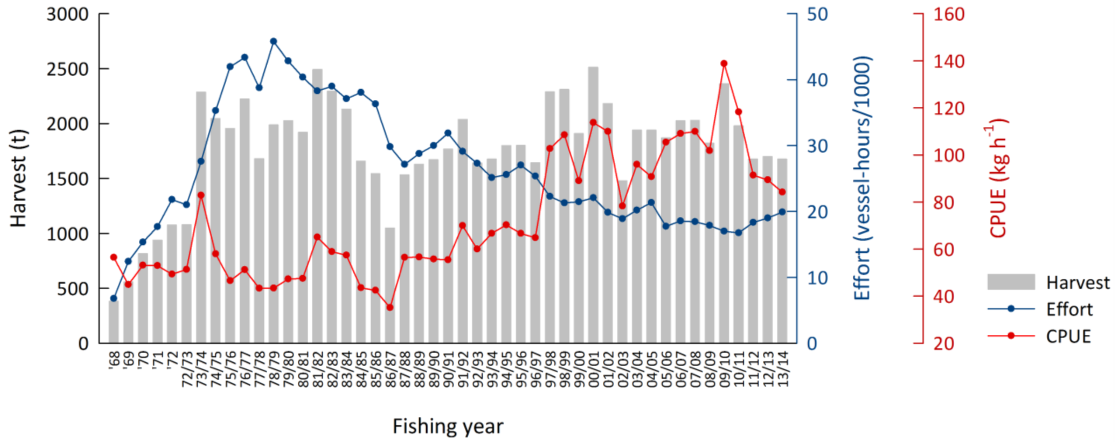


Figure 3.6. Annual harvest, effort and CPUE in the SGPF from 1968–2013/14.

A total of 54 nights was fished by the fleet in 2013/14, the same as last year and the most since 2004/05 (58 nights). With a total effort of 19,901 h expended over 2,078 vessel-nights, this equates to a mean of 9.58 h vessel-night^{-1}. Analysis of effort data since 1990/91 demonstrated a significant relationship between the number of nights and hours fished by the fleet (LR: $R^2 = 0.98$, $p < 0.001$), with an annual mean of 9.36 h vessel-night^{-1} over this 24-year period.

Annual CPUE has varied greatly over the fishery's history, with two distinct periods. Over the 30-year period from 1968 to 1996/97, CPUE ranged between 35 and 83 kg h^{-1} with an annual mean of 56 kg h^{-1}, whereas during the 17 years since 1997/98, higher CPUEs were obtained, ranging between 78 and 139 kg h^{-1} with an annual mean of 102 kg h^{-1} (Figure 3.6). The CPUE for the 2013/14 fishing year, at 84.2 kg h^{-1}, is the second lowest for the latter period, the lowest since the low harvest year of 2002/03, 61% of the peak CPUE of 2009/10 (138.8 kg h^{-1}) and 6% lower than 2012/13 (89.4 kg h^{-1}).

3.2.2. Seasonal trends

Prior to the introduction of temporal closures in 1978/79, prawns were caught throughout the year, with greatest monthly harvests in April and the smallest harvests from July to September (Figure 3.7). Since then, most of the annual harvest has been taken over six months, in November and December, and March to June, with greatest harvests in April and May, while negligible or no fishing took place in January and July to September. A similar pattern was fished in 2013/14, although a small harvest was taken in the first two days of July 2014 at the end of the lunar cycle for trawling.

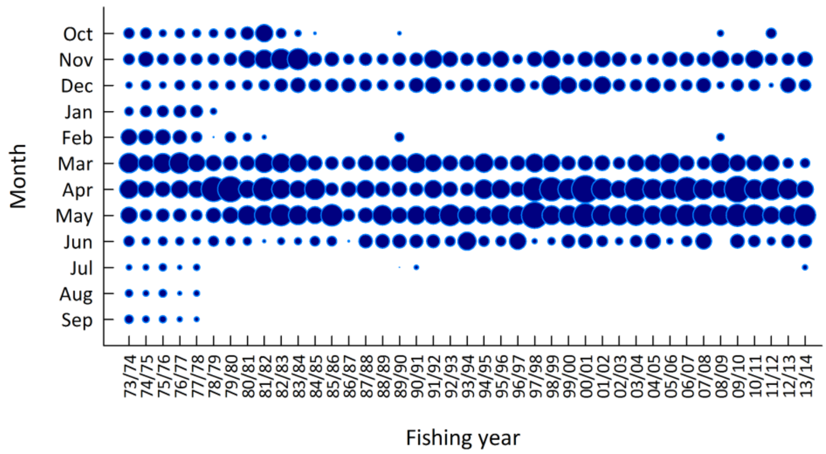


Figure 3.7. Monthly distribution of annual harvest from 1973/74–2013/14. Note: bubble area is proportional to monthly harvest.

In consecutive years between 1981/82 and 1986/87, annual harvest declined from the record high of 2,491 t to the record low of 1,048 t (Figure 3.8). This period of decline followed consecutive increases in the pre-Christmas harvest (i.e. October to December, during the early spawning period) from 297 t in 1979/80 to 833 t in 1983/84. This is the only period in the history of the fishery that pre-Christmas harvest has exceeded 500 t in consecutive years (1981/82–1983/84). Since monthly catch and effort logbooks were introduced in 1973/74, the pre-Christmas harvest has exceeded 500 t on five separate occasions (1991/92, 1995/96, 1998/99, 2001/02 and 2010/11). Each time, a decline in annual harvest was recorded in the following year. The pre-Christmas harvest of 434 t for 2013/14 is only marginally greater than the annual mean since 2004/05 (432 t). However, it represents the first time since 2001/02–2002/03 that the pre-Christmas harvest in consecutive years (i.e. combined with 2012/13) has made up more than one-quarter of the annual harvest.

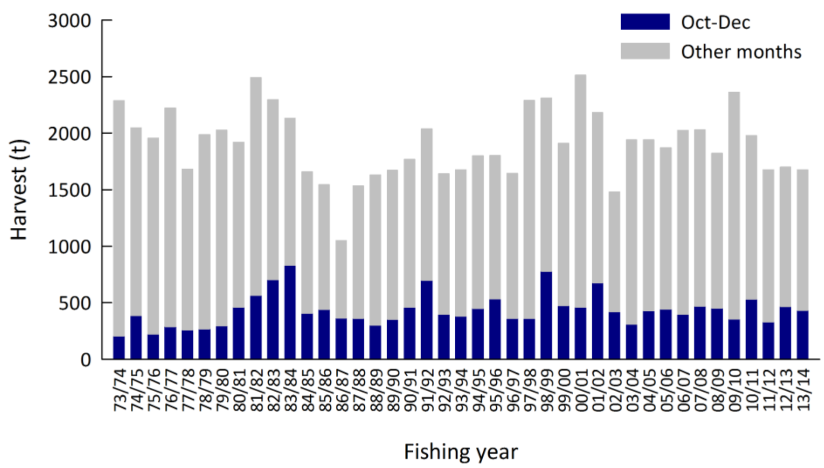


Figure 3.8. Harvest during main spawning period (October–December) relative to harvest in other months from 1973/74–2013/14.

3.2.3. Regional trends

The distribution of annual harvest by region has changed substantially since 1988/89 when regions were first aligned with boundaries of the currently-used fishing blocks. Of the ten regions, the three regions in the upper gulf, North, Middlebank/Shoalwater and Wallaroo, have collectively made up 63-84% of the annual harvest (mean: 74%). The fishing dynamic between the North and Wallaroo regions is the main influence on the distribution of harvest (Figure 3.9). A significant inverse relationship was found between the annual harvests from these two regions since 1988/89 (LR: R^2 = 0.70, p < 0.001). This inverse relationship was also observed in 2013/14. The harvest of 491 t from the North region was double the harvest in 2012/13 and the highest since 1996/97, whereas the harvest of 305 t from Middlebank/Shoalwater and 266 t from Wallaroo were 47% and 12% less than respective harvests in 2012/13 and the lowest in two decades (1992/93–1993/94). The 2013/14 harvest from Wallaroo in particular represents the fourth consecutive decline since 2009/10 when a record high of 1,202 t was harvested from that region.

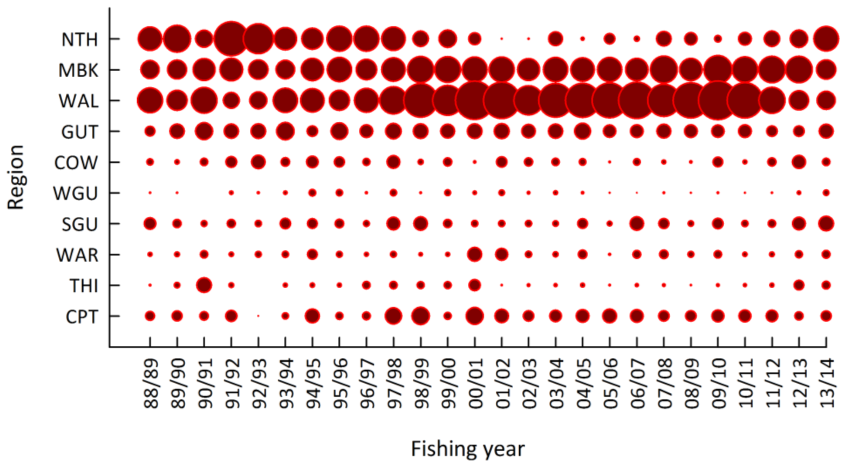


Figure 3.9. Regional distribution of annual harvest from 1988/89–2013/14. Note: bubble area is proportional to regional harvest. See Figure 1.1 for abbreviations of regions.

Annual harvests in 2013/14 for the Gutter (164 t), West Gutter (27 t), South Gutter (183 t) and Wardang (51 t) regions, albeit at relatively modest levels, were the highest recorded for several years (Figure 3.9). Since 1988/89, the coefficient of variation (CV) for annual harvest by region has ranged between 0.87 and 1.70. A CV of 0.89 in 2013/14 was the lowest since 1997/98 (0.87), indicating that the annual harvest was more evenly dispersed among the regions than most other years.

The fishery CPUE generally declines with latitude, with CPUE being higher in the North, Middlebank/Shoalwater, Wallaroo and Main Gutter regions than regions further south. While a similar regional trend was observed in 2013/14, the relatively low CPUE for the whole fishery (Section 3.2.1) was also evident across the regions, where CPUEs were less than their respective mean for the previous nine years (2004/05–2012/13), except Thistle (Figure 3.10).

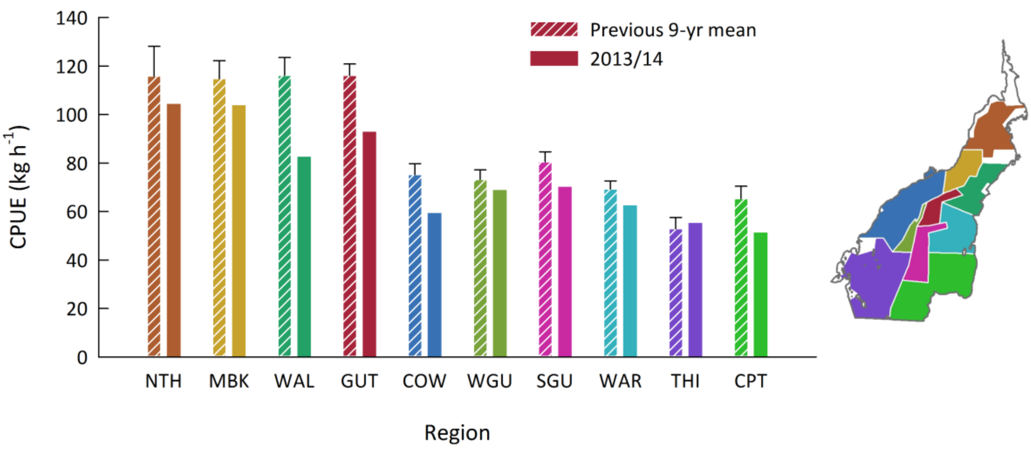


Figure 3.10. Comparison of mean CPUE by region in 2013/14 (solid bars) with the mean annual CPUE (±1 SE) of the previous 9 years (2004/05–2012/13). See Figure 1.1 for abbreviations of regions. Regions are presented in an approximately north (NTH) to south (CPT) orientation.

3.2.4. Prawn size

In 1978/79, small prawns (20+ grade) made up more than 40% of the annual harvest. Since 1998/99, however, this size category has generally contributed less than 7%. (Figure 3.11). This reduction in the proportion of small prawns has been offset by at least two-fold increases in the proportions of large (10/15 grade, from 22% to 43-55%) and extra-large prawns (U10 grade, from 7% to 15-26%) over these same periods (Figure 3.11). In 2013/14, the proportion of small prawns of 6.9% was at the upper end of its range since 1998/99 while the proportion of large prawns of 42.6% was at the lower end of its range.

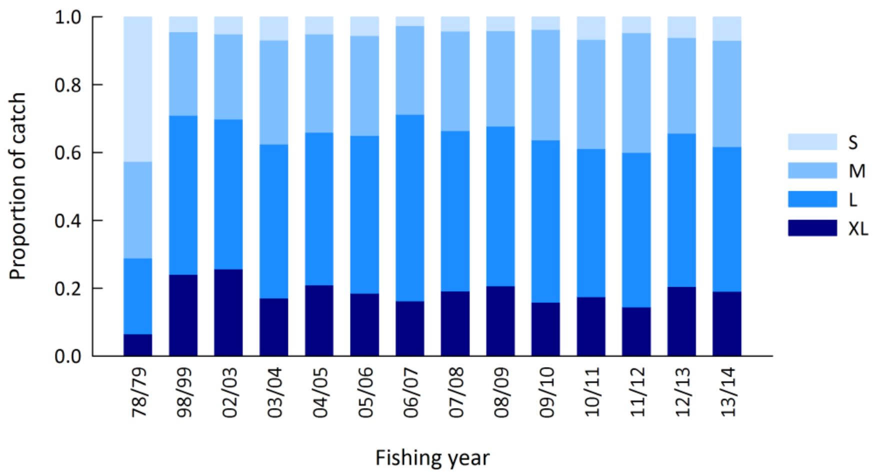


Figure 3.11. Size composition of prawns in the commercial catch in 1978/79, 1998/99, and from 2002/03–2013/14. Abbreviations: S, small (20+ grade); M, medium (16/20); L, large (10/15); XL, extra-large (U10).

A mean bucket count of 220 pp7kg was calculated for the 2013/14 fishing year. This suggests that, compared to the annual mean of 215 pp7kg since 2002/03, prawn sizes for the 2013/14 harvest were slightly smaller than average. Of a total of 2,076 vessel-nights fished in 2013/14, the frequency of occurrence at which bucket counts were greater than 220 (46%), 250 (18%) and 280 (4%) were all the highest recorded since 2002/03 (Table 3.1).

Table 3.1. Number of vessel-nights each fishing year (from 2002/03 to 2013/14) where the mean nightly bucket count was greater than 220, 250 and 280 pp7kg.

Fishing year	$\overline{pp7kg_Y}$	Total nights	$\overline{pp7kg_N}$ >220		$\overline{pp7kg_N}$ >250		$\overline{pp7kg_N}$ >280	
			Nights	%	Nights	%	Nights	%
2002/03	206	1,956	543	28%	133	7%	24	1%
2003/04	221	2,088	921	44%	270	13%	67	3%
2004/05	214	2,251	772	34%	125	6%	24	1%
2005/06	216	1,903	636	33%	116	6%	16	1%
2006/07	209	1,978	230	12%	34	2%	3	0%
2007/08	213	1,938	702	36%	157	8%	13	1%
2008/09	211	1,974	604	31%	103	5%	10	1%
2009/10	217	1,902	689	36%	122	6%	18	1%
2010/11	221	1,787	801	45%	185	10%	18	1%
2011/12	216	1,990	745	37%	147	7%	12	1%
2012/13	215	2,085	777	37%	205	10%	32	2%
2013/14	220	2,076	965	46%	372	18%	87	4%
Mean	215	1,994	699	35%	164	8%	27	1%

3.3. Catch standardisation

The modelling of survey catches in the SGPF was carried out on survey data from 2004/05–2013/14 when a consistent and regular survey program was implemented. The standardised model fit showed some difference from raw data over the available time series, but not in overall trend (Figure 3.12). Region (β_2), tide direction (β_4), lunar phase (β_7), year-survey (β_1) and vessel (β_3) were all highly significant (Table 3.2); however, a low overall goodness-of-fit (adjusted R^2 value 0.34) suggests other unaccounted sources of variability.

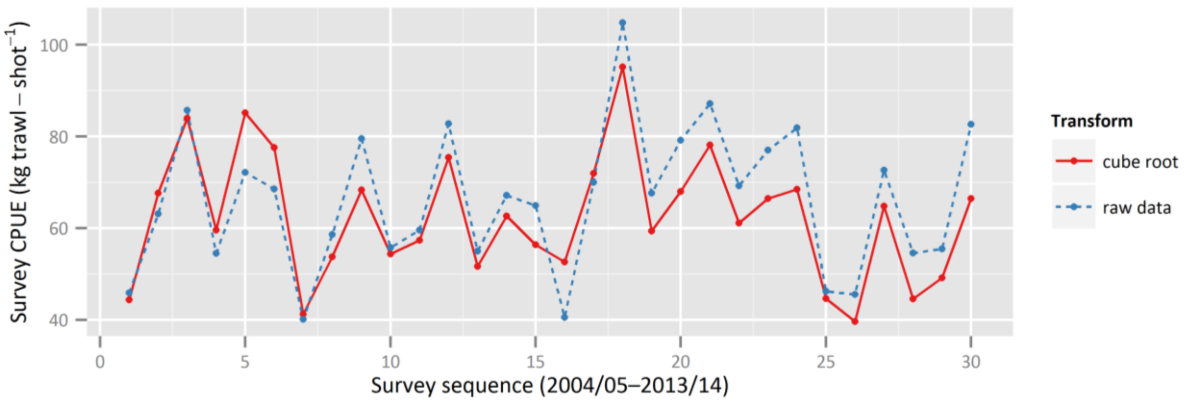


Figure 3.12. Comparison of model-predicted mean survey CPUE in the SGPF with raw data from 2004/05–2013/14.

Table 3.2. Analysis of deviance (Type II test) for the GLM used to standardise survey CPUE. Abbreviations: SS, sum of squares; df, degrees of freedom; *F*, *F*-statistic. $R^2_{adj} = 0.34$.

Effect	SS	df	*F*
Fishing year-survey (β_1)	459.4	29	20.1***
Region (β_2)	1725.3	8	273.2***
Vessel (β_3)	141.3	34	5.3***
Tide direction (β_4)	75.4	3	31.8***
Lunar phase (β_7)	16.5	1	20.9***
Residuals	4576.8	5799	NA

Significance: *** $p < 0.001$.

The modelling of fishery catches was carried out on daily logbook data from 1990/91–2013/14. The standardised model fit showed some difference from raw data over the available time series, but adequately captured the overall trend (Figure 3.13). Effort (β_{10}) was by far the most influential variable on catches, although lunar phase (β_7 and β_8), region (β_2), year-month (β_1) and vessel (β_3) were also highly significant (Table 3.3). Overall goodness-of-fit was high, with an adjusted R^2 value of 0.70.

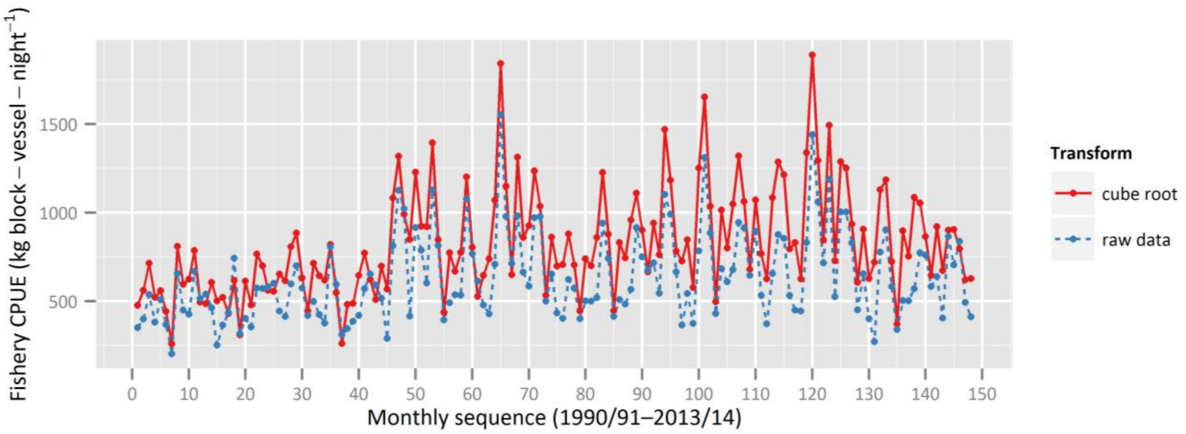


Figure 3.13. Comparison of model-predicted mean fishery CPUE in the SGPF with raw data from 1990/91–2013/14.

Table 3.3. Analysis of deviance (Type II test) for the GLM used to standardise fishery CPUE. Abbreviations: SS, sum of squares; df, degrees of freedom; *F*, *F*-statistic. $R^2_{adj} = 0.70$.

Effect	SS	df	*F*
Fishing year-month (β_1)	76616	147	322***
Region (β_2)	15653	9	1076***
Vessel (β_3)	3103	38	51***
Lunar phase (β_7)	7225	1	4470***
Lunar phase (¼ lag) (β_8)	4399	1	2722***
Effort (β_{10})	159425	1	98624***
Residuals	114935	71102	NA

Significance: *** $p < 0.001$.

Model parameter coefficients (Appendix B) indicate, for surveys and fishing, a general decline in CPUE from north to south of the gulf (i.e. region effect), and, for surveys, CPUE was higher when the trawl net was towed in the same direction as the tide (i.e. tide direction effect).

For those months in which surveys and fishing have taken place since 2004/05, a high correlation is evident between normalised survey and fishery CPUE (Figure 3.14), indicating that the survey CPUE trend is representative of the abundance of prawns and the subsequent harvest.

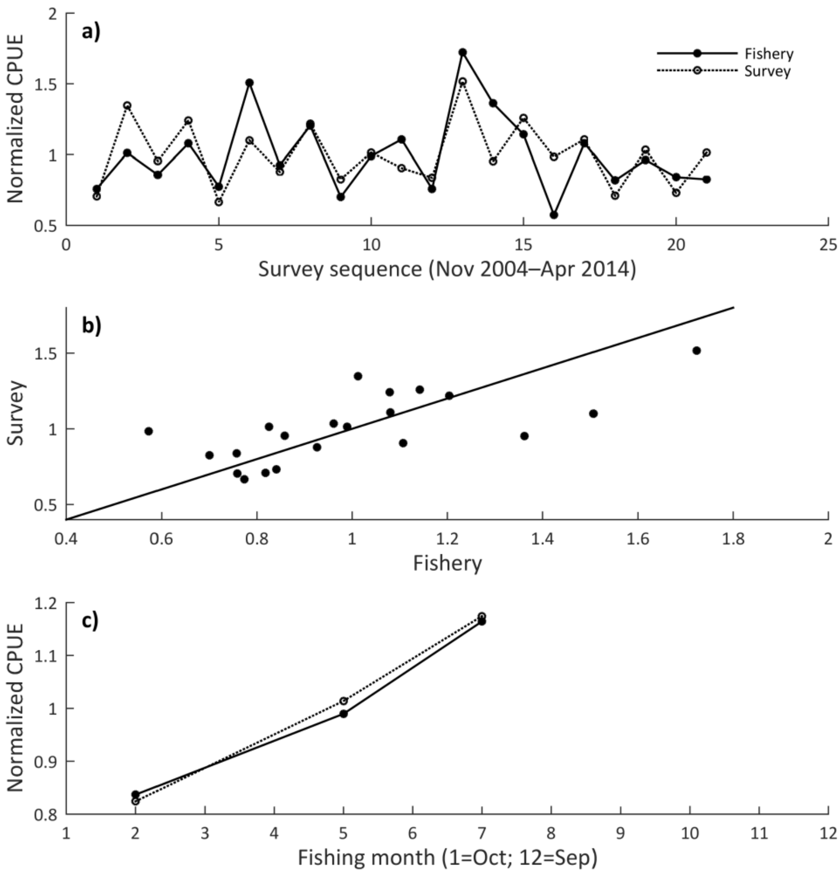


Figure 3.14. Comparison of standardised survey and fishery CPUE trends in the SGPF by: a) survey sequence; b) regression; and c) fishing month. Note: CPUE data were normalised to ensure trends were on a similar scale.

3.4. Other research

3.4.1. Juvenile prawn survey

False Bay has consistently been the most productive site over the years for juvenile prawns (Figure 3.15). Since the peak of 11.79 (± 1.57) juveniles m^{-2} in 2000, relative mean abundance (± SE) at False Bay declined over consecutive surveys to the lowest recorded at 0.72 (± 0.04) juveniles m^{-2} in 2013. In 2014, however, relative abundance increased to 3.47 (± 0.10) juveniles m^{-2}, the highest since 2009 (3.85 ± 0.29 juveniles m^{-2}). At Port Pirie, relative abundance since 1993 had ranged between 0.46 (± 0.03) and 1.69 (± 0.13) juveniles m^{-2} in 2012 and 2009, respectively. However, the abundance of 0.33 (± 0.14) juveniles m^{-2} in 2014 is currently the lowest recorded for that site.

The declining trend in abundance of juveniles at False Bay from 2000–2012 was also observed at three other sites that were consistently surveyed (Mount Young, The Spit and Fifth Creek) (Figure 1.1). These sites were removed from the annual survey program in 2013 due to cost and their location within prohibited zones of South Australia's Marine Parks.

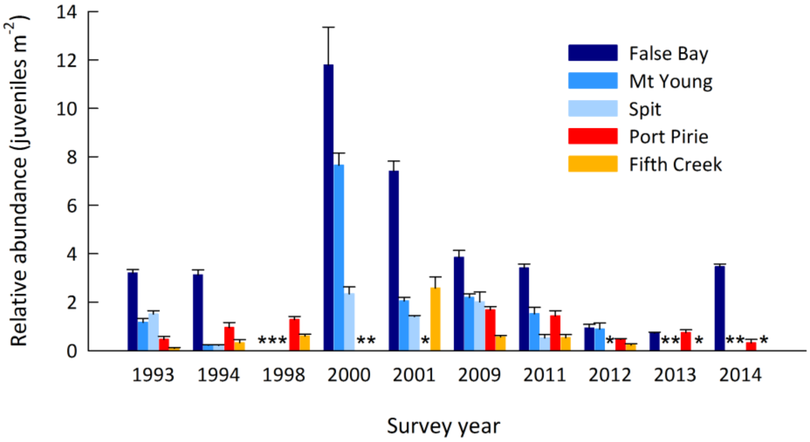


Figure 3.15. Relative abundance of juvenile western king prawns at five key sites in upper Spencer Gulf during March/April from 1993–2014. Asterisk (*) indicates site was not surveyed.

3.4.2. Tagging study

As of March 2015, 71 of 2,562 (2.8%) female prawns and 47 of 3,431 (1.4%) male prawns were recaptured after being tagged in June 2012 and June 2013 (Table 3.4). The spatial distribution of recaptured prawns was similar to the distribution and intensity of trawling effort during the 2012/13 fishing year (Figure 3.16). Most recaptured prawns (51%) moved in a north-east direction (mean: 16.0 km) from South Gutter into the Gutter. Others moved relatively short distances in a north-west direction within the South Gutter (25%; mean: 4.9 km), large distances in a south-west direction towards the Thistle region (16%; mean: 18.9 km), or large distances in a south-east direction (7%; mean 33.6 km) (Figure 3.16 and Table 3.5). While female prawns moved shorter distances than males (females: 13.3 km; males: 19.8 km), they grew faster (females: 4.6 mm yr^{-1}; males: 3.0 mm yr^{-1}) and reached a larger size than males (females: 42.1 mm CL; males: 37.7 mm CL) (Table 3.4).

Table 3.4. Summary statistics of the prawn tagging study conducted in June 2012 and June 2013 in the southern regions of Spencer Gulf.

Measure	Females		Males	
	Mean	Range	Mean	Range
Tagged				
Total	2,562		3,431	
Carapace length (mm)	39	26-62	36	23-52
Recaptured				
Total	67		43	
Carapace length (mm)	42.1	34.3-56.1	37.7	29.0-46.0
Time at liberty (d)	193	141-510	213	142-363
Growth rate ($mm.yr^{-1}$)	4.6	0.0-18.0	3.0	0.0-11.3
Distance (km)	13.3	0.7-95.2	19.8	1.7-85.8

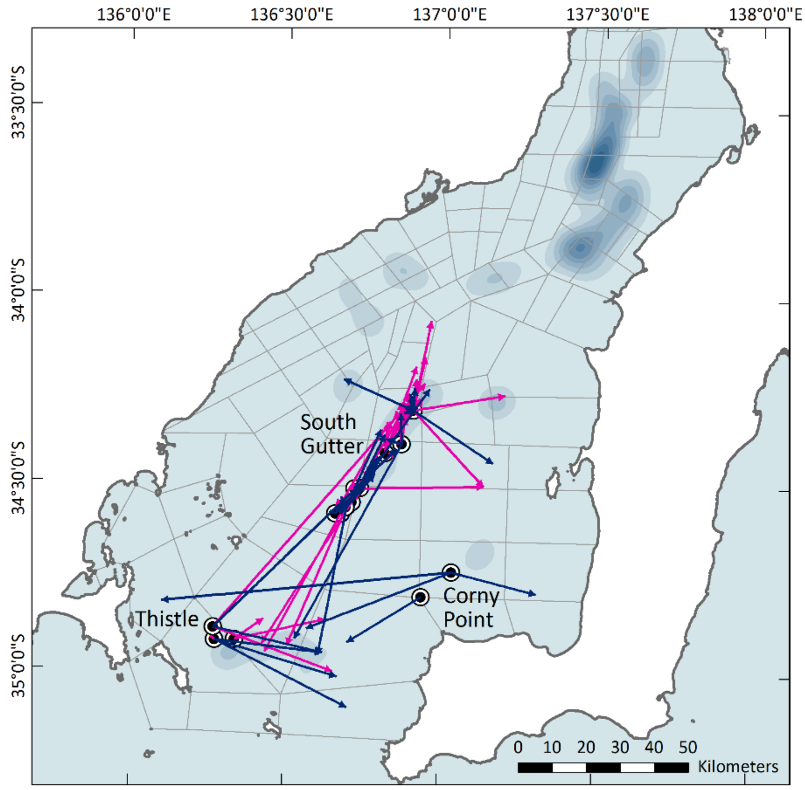


Figure 3.16. Movement vectors of recaptured western king prawns that were tagged and released in the southern regions of Spencer Gulf in June 2012 and June 2013. Males, blue vectors; females: pink vectors. A kernel density plot of the distribution and intensity of trawling effort for the 2012/13 fishing year is also shown.

Table 3.5. Direction of movement of prawns from tagging to recapture.

Direction	Total	Distance (km)	
		Mean	Range
NE (0-90°)	56	16.0	0.7-95.2
SE (90-180°)	8	33.6	25.9-43.8
SW (180-270°)	18	24.5	2.3-85.8
NW (270-360°)	28	4.9	1.5-22.5

3.5. Fishing strategy assessment

All three fishery-independent surveys were conducted during 2013/14. The mean catch rate of prawns larger than 20+ grade for the November survey was 3.11 lb min^{-1}, which, under the revised pre-Christmas catch decision rules, led to a catch cap for the fleet of 450 t (Table 3.6). Mean survey catch rates of 4.14 lb min^{-1} for all prawns (total) and 1.03 lb min^{-1} for 20+ grade were both above their lower thresholds (3.5 and 0.4 lb min^{-1}, respectively), resulting in a standard survey result. The total and 20+ grade catch rates of 4.26 and 1.33 lb min^{-1} for the February survey were both below their respective thresholds (4.4 and 1.8 lb min^{-1}, respectively). Whilst the outcome of the February survey was a conservative result, a standard fishing strategy was subsequently adopted since, under the 2007 Plan, a conservative fishing strategy is only enforced after two consecutive poor survey results. For the April survey, mean catch rates of 7.34 lb min^{-1} for all prawns and 1.64 lb min^{-1} for 20+ grade were both above their lower thresholds (5.9 and 1.5 lb min^{-1}, respectively), resulting in a standard survey result and fishing strategy for the remainder of the season.

Table 3.6. Summary of 2013/14 survey results and the implications on fishing strategy development. Values highlighted in red indicate that the catch rate measure was below the lower threshold (see Table 2.3). Where validation of the data resulted in a different outcome, these are shown in parentheses. NA, not applicable.

Survey month	Survey catch rate (lb min^{-1})			Survey result	Nature of strategy	Primary decision rule
	Total	20+ grade	>20+ grade			
November	4.14	1.03 (1.12)	3.11	Standard	Standard	≤450 t catch cap
February	4.26 (4.33)	1.33 (1.53)	NA	Conservative	Standard*	≤220 pp7kg
April	7.34 (7.36)	1.64 (1.76)	NA	Standard	Standard	≤240 pp7kg

* Despite a conservative result for the February survey, a standard fishing strategy was allowed under the 2007 Plan (i.e. two consecutive surveys with a conservative result are required before a conservative strategy is enforced).

At the end of the 2013/14 fishing year, a series of checks were performed on the survey data to verify their accuracy and resolve any errors. This validation process resulted in higher catch rates (up to 15% greater) for each survey and most categories than those determined immediately after surveys (for real-time management); however, these differences would not have led to a different survey result or fishing strategy.

In 2013/14, a total of 281 blocks were fished across seven fishing periods (Table 3.7). For 61 of these blocks (22%), their catches did not meet the size criteria of the standard fishing strategies. The catches from these 61 blocks was 343 t, which represented 20% of the total annual harvest. Of the 54 nights fished by the fleet, the average prawn size did not meet the size criteria on four nights (7%) and the average catch did not meet the minimum catch criteria on two nights (4%) (Table 3.7).

Table 3.7. Summary of fishing statistics regarding size and catch criteria for each fishing period in 2013/14. Blue lines indicate the timing of the three stock assessment surveys with respect to the fishing periods.

Fishing period	Target size (pp7kg)	Total catch (t)	Total catch outside size criteria (t)	Blocks fished	Blocks outside size criteria	Nights fished	Nights outside size criteria	Nights outside catch criteria
1 (4-10 Nov)	<250	211	85	36	16	6	2	0
2 (29 Nov – 10 Dec)	<250	224	67	46	12	11	1	0
3 (29 Mar – 6 Apr)	<220	236	14	35	6	9	0	0
4 (25-26 Apr)	<220	58	0	17	0	2	0	0
5 (29 Apr – 7 May)	<240	383	0	46	1	8	0	0
6 (25 May – 6 Jun)	<240	454	121	60	10	13	1	1
7 (25 Jun – 2 Jul)	<240	110	56	41	15	5	0	1
Total		1,675	343	281	60	54	4	2

3.6. Fishery performance

The PIs in the 2007 Plan are no longer used to measure performance of the fishery as they have been superseded by those developed in the 2014 Plan. There are now seven key biological PIs. Two of these, the recruitment index and mean commercial CPUE, remain from the 2007 set of indicators. All seven PIs were above their LRPs or at acceptable levels. Compared to the end of 2012/13, when the stock status was considered to be sustainable (on the weight of evidence), three PIs demonstrated substantial improvement in 2013/14 (weighted mean survey catch rate, recruitment index and mean egg production), another three were maintained at acceptable levels (100% of commercial daily logbooks returned, annual update of research plan, and all three stock assessment surveys completed), and only one had declined (mean commercial CPUE).

Table 3.8. Performance of the Spencer Gulf Prawn Fishery in 2012/13 and 2013/14 with respect to the key performance indicators and reference points in the 2014 Management Plan (PIRSA 2014).

Performance indicator		Limit reference point	2012/13	2013/14
1.	Weighted mean survey catch rate of adult prawns	≥1.75 lb min^{-1}	3.55 lb min^{-1}	4.25 lb min^{-1}
2.	Recruitment index ($\sqrt{\text{recruits nm}^{-1}}$)	>35	34.1	43.3
3.	Mean egg production	>500 million eggs trawl-hour^{-1}	643 million eggs trawl-hour^{-1}	806 million eggs trawl-hour^{-1}
4.	Mean commercial CPUE	>80 kg trawl-hour^{-1}	89.4 kg h^{-1}	84.2 kg h^{-1}
5.	Return of commercial daily logbooks for all licences and all nights fished	100%	100%	100%
6.	Update of strategic research plan	Annually	✓	✓
7.	Fishery-independent surveys conducted to inform annual status	All three surveys	✓	✓

One of the features of the revised harvest strategy in the 2014 Plan is the calculation of the weighted mean catch rate of adult prawns from all three stock assessment surveys (PI 1 in Table 3.8) and linking this value with a stock status classification based on historic reference points. The validated survey catch rates of adult prawns from all three surveys conducted in 2013/14 were greater than corresponding surveys in 2012/13 (Figure 3.17). The weighted mean catch rates of adult prawns for 2012/13 and 2013/14 were 3.55 lb min^{-1} and 4.25 lb min^{-1}, respectively, both of which are above the LRP of 1.75 lb min^{-1} and the trigger reference point of 2.50 lb min^{-1}.

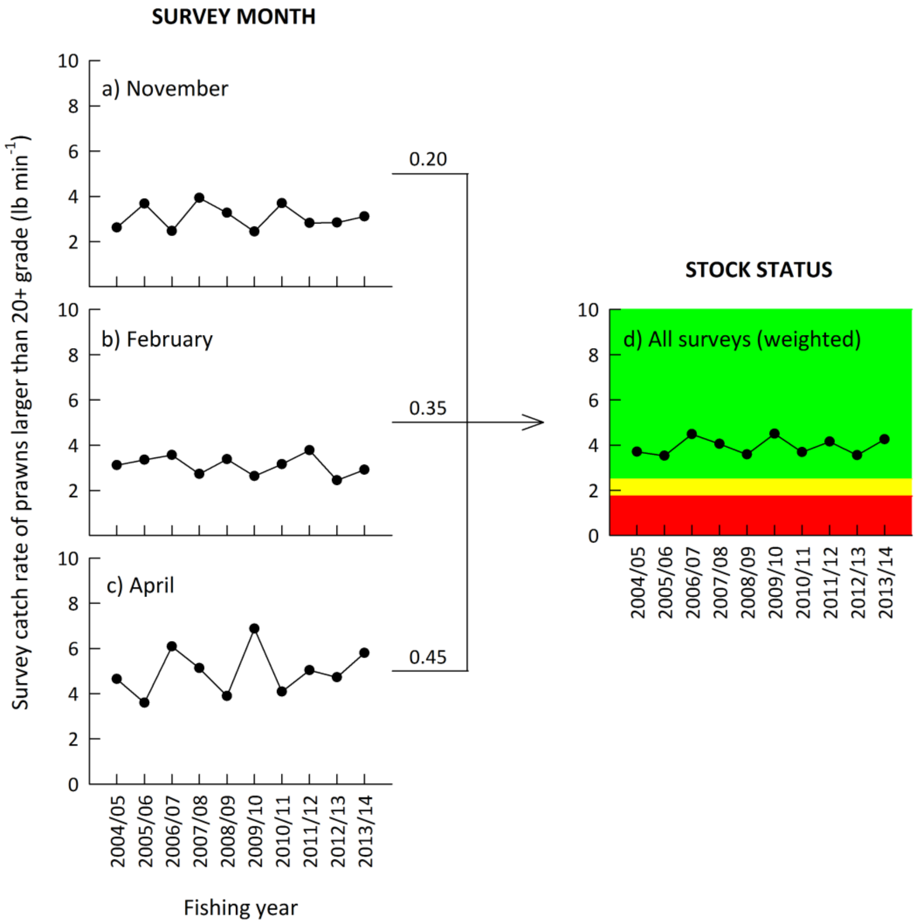


Figure 3.17. Mean catch rate of prawns larger than 20+ grade for all surveys, and the determination of stock status based on a weighted mean of the survey results. Stock status categories: green = sustainable stock; yellow = transitional; red = overfished.

For comparative purposes only, performance measures with respect to the indicators in the 2007 Plan are shown in Table 3.9. Of the five key biological PIs, two were below their LRPs for 2013/14: 1) the total commercial harvest (1,675 t) was less than the LRP of 1,800 t for the third consecutive year; and 2) the percentage of vessel-nights where the 7 kg bucket count of prawns exceeded 280 (4.2%) was more than double the LRP of 2% (Table 3.9).

Table 3.9. Performance of the Spencer Gulf Prawn Fishery in 2012/13 and 2013/14 with respect to the key performance indicators and limit reference points in the 2007 Management Plan (Dixon and Sloan 2007).

Performance indicator	Limit reference point / acceptable level	2012/13	2013/14
1. Recruitment index ($\sqrt{\text{recruits nm}^{-1}}$)	>35	34.1	43.3
2. Total commercial catch	>1,800 t	1,699 t	1,675 t
3. Mean commercial CPUE	>80 kg h^{-1}	89.4 kg h^{-1}	84.2 kg h^{-1}
4. % vessel nights with mean size >280 pp7kg	<2%	1.5%	4.2%
5. Indices of future and current biomass (defined in the 2007 Plan)	Neither index is below lower threshold levels in two consecutive surveys	✓	✓

4. DISCUSSION

4.1. Information sources used for assessment

Substantial information was available to assess the western king prawn stock in the SGPF for 2013/14, including: 1) documentation of historic and current management arrangements of the fishery (Dixon and Sloan 2007); annual stock assessment reports over more than a decade (Carrick 2003; Dixon *et al.* 2005; 2007; Dixon and Hooper 2008; Dixon *et al.* 2009; 2010; 2012; 2013; Noell *et al.* 2014); 2) comprehensive biological synopsis of the species; 3) fishery-independent data (obtained from regular stock assessment surveys); and 4) fishery-dependent catch, effort and prawn size data.

4.1.1. Stock assessment surveys

Fundamental to the long-term sustainability of the SGPF are stock assessment surveys. Since 1982, multiple surveys have been conducted each year, most frequently in November, February and April. The distributions of catch rate and prawn size obtained from these three surveys have provided the basis for obtaining indices of relative biomass throughout the fishing year (since 2004/05 when a consistent spatial and temporal survey design was adopted) and the subsequent development of fishing strategies. For this reason, surveys are conducted around the new moon to maximise catch rates and optimise the fishing strategy.

Results from November, February and April stock assessment surveys varied in 2013/14. The mean catch rate for prawns larger than 20+ grade (as an index of adult biomass) in the November survey translated into a 450 t fleet catch cap for the November and December fishing periods in accordance with the pre-Christmas harvest decision rules. The entire catch cap was taken by the fleet over 17 nights. As the mean survey catch rates for 20+ grade (‘recruits’) and prawns larger than 20+ grade (‘adults’) were both above the lower thresholds in the 2007 Plan, the November survey yielded a standard result. For the February survey, neither catch rate measure performed as well, with both falling below their thresholds and yielding a conservative result. Despite a conservative result, the 2007 Plan acknowledges that external factors can have a substantial effect on catch rates and therefore includes the provision that a conservative fishing strategy is only enforced after two consecutive surveys have produced a conservative result. It should also be noted that the lower and upper catch rate thresholds in the 2007 Plan that delineate the nature of the fishing strategies were designed to maintain the relative biomass within historic levels and assumed to be above a limit reference point that would identify when overfishing had occurred. As the previous survey in November yielded a standard result, a standard strategy was adopted after the February survey. The catch rates in the April survey for 20+ grade and prawns larger than 20+ grade returned above the lower thresholds to allow the fleet to fish to a standard fishing strategy for the remainder of the season.

The development of fishing strategies immediately after stock assessment surveys is one of the features that have placed the SGPF as a leader in co-management. However, a limitation to this real-time management system was highlighted in the previous stock assessment when validation of survey data revealed a difference between validated and unvalidated April survey results, which ultimately led to a different fishing strategy (Noell *et al.* 2014). Once again, in 2013/14, there were differences between unvalidated and validated data, although this time it did not affect the outcome. Closer examination of the survey data for both years indicates that most errors were systematic, and owing to an underestimation of the 20+ grade catch in the electronic logbooks compared to the unloaded grade weights (assumed correct). This resulted in the unvalidated mean catch rate being 7.3-15% less than the 'true' catch rate for 20+ grade. This issue was first raised two years ago, and the observation that it is still occurring emphasises the importance of the ongoing education and awareness of stock assessment surveys given to skippers, crew and observers.

Egg production in the November 2013 survey was the highest recorded for November surveys since 2004. This is likely to be attributed to conservative fishing over the last two years (1,675 t harvested in 2011/12; 1,699 t harvested in 2012/13) relative to the long-term average of ~1,900 t. If annual harvest in any given year is depressed relative to the biomass, it would be reasonable to expect that the opportunity for growth and sexual maturation would occur for a greater proportion of the stock, thus leading to increased egg production in the following November survey as observed in 2012 and 2013. Following this line of reasoning, and assuming a stable biomass, it is expected that the third consecutive annual harvest of less than 1,700 t in 2013/14 (1,675 t) will again lead to a high egg production estimate for November 2014 in the next stock assessment.

The survey catch rate of 20+ grade prawns has traditionally been used as an indicator of future biomass, particularly in February surveys, when it is expected that most of the cohort spawned ~15 months earlier have recruited to the fishable stock. The (validated) mean survey catch rate for 20+ grade prawns in February 2014 was relatively low and just below the lower threshold; however, the recruitment index, which is a key PI, was considerably higher than the LRP. The reason for this inconsistency between the 20+ grade catch rate and the recruitment index from the same survey may lie in the differences in how each measure is derived. The 20+ grade catch rate accounts for the entire survey catch of 20+ grade prawns from all survey shot locations, whereas the recruitment index is derived from male prawns <33 mm CL and female prawns <35 mm CL in length-frequency samples collected from a subset of survey locations in the north of the gulf. It is not clear which is the preferred measure of recruitment as both have their pros and cons. For example, while the carapace length of prawns in the recruitment index may represent newly-recruited prawns better than the catch weight of 'small' prawns, and it is more appropriate to sample locations near the key nursery areas, it relies on the assumption that length-frequency samples collected by observers are representative of the population. To resolve these issues, a review of the February survey and a comparison of length-frequency samples and grade weights is planned to be undertaken as part of future research (Section 4.3) to determine the most cost-effective and reliable method for estimating recruitment.

4.1.2. Commercial logbook data

The 2013/14 harvest of 1,675 t was below the LRP (1,800 t) for the third consecutive year. However, breach of this reference point alone is not necessarily cause for concern. It raises the possibility of an underlying economic problem, not a stock sustainability concern, hence this measure was excluded from the revised set of PIs in the 2014 Plan. Commercial CPUE is also important from an economic perspective, and while the mean CPUE in 2013/14 of 84.2 kg h^{-1} was above the LRP (80 kg h^{-1}), it was the lowest in more than a decade.

Regional breakdown of the 2013/14 harvest demonstrated a continuation of the declining trend in harvest from the Wallaroo and Middlebank/Shoalwater regions in recent years. The reduced harvest from these traditional fishing grounds was offset by the increased harvest in the (traditionally) lightly-fished North region, which was greater than the Wallaroo or Middlebank/Shoalwater region for the first time since 1996/97. A plausible explanation for the increased harvest from the North region is that the relatively low catch rates pushed some of the fleet into more northern fishing grounds that are often characterised by relatively high densities of prawns, but at a smaller size. This is also consistent with the slightly higher than average proportion of 20+ grade prawns and bucket count (i.e. smaller prawns) obtained throughout the fishing year.

4.1.3. Catch standardisation

The assumption in many fishery assessments that abundance is proportional to catch rate necessitates the removal of factors (not related to abundance) that may influence catch rate. As part of the development of the bio-economic model for the fishery (Australian Seafood CRC Project No. 2011/750), this report provided an update of the standardisation of survey and fishery catches using generalised linear modelling to remove the influence of these factors.

In addition to the year-survey effect, region, tide direction, lunar phase and vessel had a significant influence on survey catches. Back-transformed predicted means for region and tide direction demonstrated similar effects as nominal catches, where survey catches generally declined from north to south of the gulf. Nevertheless, while standardised catches tracked the nominal trend reasonably well for the year-survey means, only 34% of the total deviance in survey catches was explained by the model (region being the most important at 25%), which indicates that 66% of the deviance was caused by unknown factors. Further work is planned to improve the standardisation of survey catch rates.

Standardisation of fishery catches fared better than for surveys, with 74% of the total deviance explained by the model. Significant variables were effort, lunar phase, region and vessel. Of these, effort had, by far, the greatest influence on catch. It is widely known that the lunar phase influences the catch rate of prawns. A much stronger lunar effect was found for fishery catches compared to survey catches, but that is due to a lack of contrast in the lunar phase during surveys since surveys are consistently done on the night before and on the new moon, whereas fishing occurs over a larger part of the lunar cycle.

4.1.4. Other research

Extensive prawn tagging work (>150,000 tagged, ~9,000 recaptured) undertaken by Carrick (2003) in Spencer Gulf between 1984 and 1992 has been fundamental in understanding the generalised movement patterns of prawns within the gulf. In June 2012 and June 2013, industry and SARDI tagged and released an additional 6,000 prawns in the southern regions of the gulf. The specific aim of this work was to determine whether prawns from these regions were more likely to move out of the gulf or remain in the gulf and contribute to spawning and future biomass, as this was considered to have implications for fishing strategy development for the south towards the end of the fishing year. At the time of preparing this report, 110 prawns had been recaptured, and while the results clearly showed that relatively few recaptured prawns had moved south from South Gutter towards the entrance of the gulf, most had moved smaller distances north toward the Gutter region. Although there was relatively less fishing and recaptures toward the entrance to the gulf, this study demonstrated that prawns were capable of moving out of the gulf, but no conclusions could be drawn on the proportions.

4.2. Stock status

The SGPF has demonstrated to be a sustainable fishery, with annual harvests maintained between 1,600 t and 2,400 t for the last 40 years. Despite this long and stable history of commercial catches and recruitment, it became evident in recent years that there were a number of limitations in the harvest strategy. Specifically, the harvest strategy in the 2007 Plan: 1) lacked a LRP that determined the level below which the fishery was considered recruitment overfished; 2) did not clearly outline how stock status would be determined; and 3) lacked a recovery strategy if the fishery was recruitment overfished.

During the 2012/13 fishing year, the third management plan for the fishery underwent development. This new management plan (the ‘2014 Plan’) came into effect at the start of the 2014/15 fishing year and features a revised harvest strategy (PIRSA 2014) that addresses the limitations of the previous harvest strategy. Briefly, it can be described as a management framework that applies at three temporal scales (annual/stock status, ‘inter-survey’ harvest period, and daily), with decision rules pre-determined at each level.

The revised harvest strategy in the 2014 Plan uses the weighted mean catch rate of adult prawns from all three stock assessment surveys as an index of the targeted biomass. This index, in turn, is used to determine the end-of-year stock status classification, the categories which are delineated by historic reference points. In the following year, the stock status, combined with a survey’s mean catch rates for adults and recruits, determines the target size and catch and/or effort parameters for subsequent fishing strategies.

Based on the application of the revised harvest strategy, the SGPF is not considered to be recruitment overfished and the current level of fishing mortality is unlikely to cause the stock to become recruitment overfished. Therefore, the resource supporting the SGPF is classified as a ‘sustainable stock’.

4.3. Future research needs

A four-year research scope has recently been agreed to by PIRSA and industry. It encompasses a more strategic approach to future research that is cost-effective, enables longer-term planning towards research objectives, and provides certainty and stability for industry and PIRSA (including SARDI) that will ultimately help to maintain the fishery's status as a leader in co-management.

The components of the four-year scope are annual determination of stock status, annual surveys of juvenile abundance and disease monitoring, biennial stock assessment reports, and 'additional' research projects focused on stock assessment development and ecosystem monitoring.

These additional projects will be undertaken during the alternate non-assessment years, and include the following activities:

1. Stock assessment development
    a. Investigate cost-effective alternatives to the February stock assessment survey for obtaining a reliable index of recruitment, whilst maintaining integrity of the harvest strategy.
    b. Investigate alternatives to the length-frequency sampling for obtaining more accurate and cost-effective estimates of recruitment and egg production, thus enabling other research activities to be undertaken by SARDI observers during surveys.
    c. Determine whether the number of trawl shot locations of the current survey design can be rationalised for stock assessment.
2. Ecosystem monitoring
    a. Develop a method for routine determination of change in the ecological footprint and develop reference points for real-time spatial management.
    b. Evaluate impacts of the fishery on the ecosystem through ongoing monitoring of selected species incidentally taken as by-catch.

Although not explicit in the four-year research scope, it is expected that there will be ongoing dialogue with fisheries management and industry regarding extension of the prawn bio-economic model and bio-physical model (FRDC Project No. 2008/011) to ensure that every opportunity is afforded to stakeholders to benefit from this important work.

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APPENDIX A

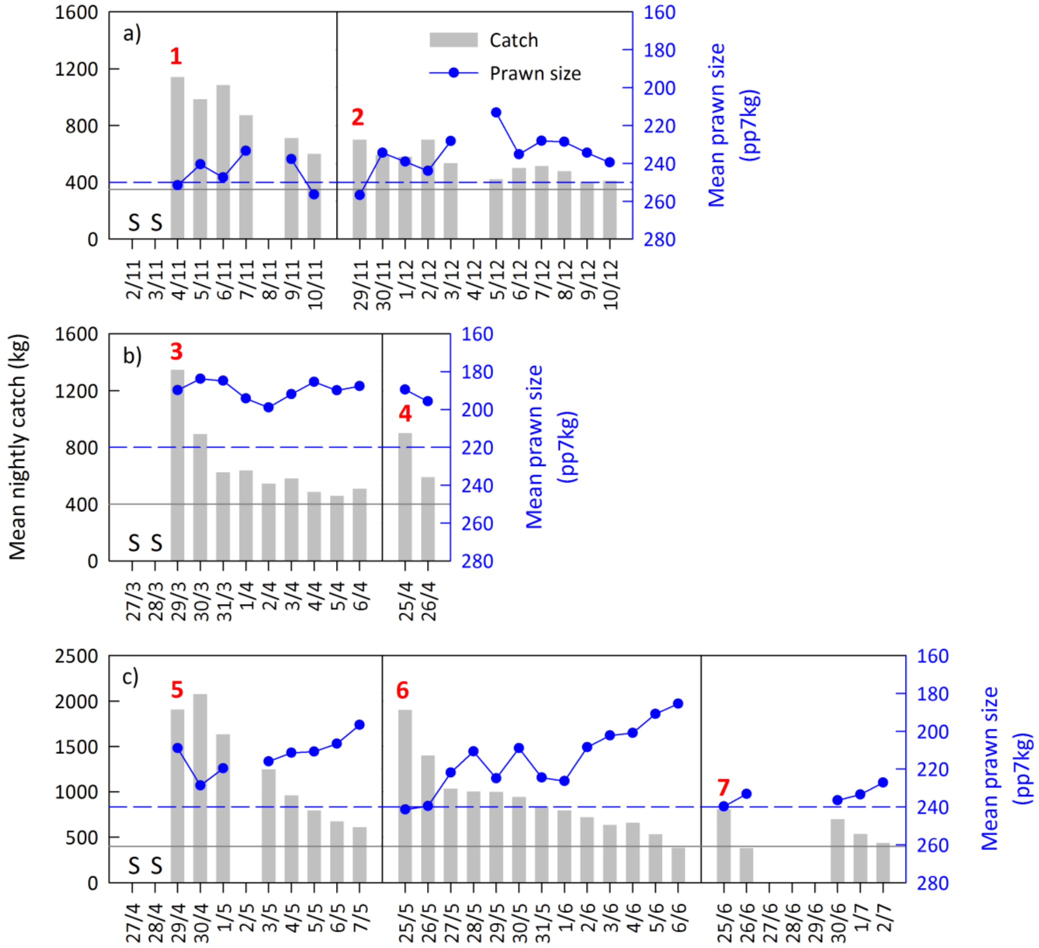

Figure A 1. Mean prawn size (blue lines/symbols) and nightly catch (grey bars) for the 54 nights fished during the 2013/14 fishing year. Plots are arranged to show the dates fished following a) November, b) February and c) April surveys. Survey dates are indicated by the letter 'S', and the seven fishing periods are indicated by numbers in red. Reference lines indicate the prawn size (blue dashed) and catch criteria (dark grey solid) implemented following the latest survey. Note: prawn size axis is shown in reverse order since a small number of prawns per 7 kg indicate large prawns (and vice versa).

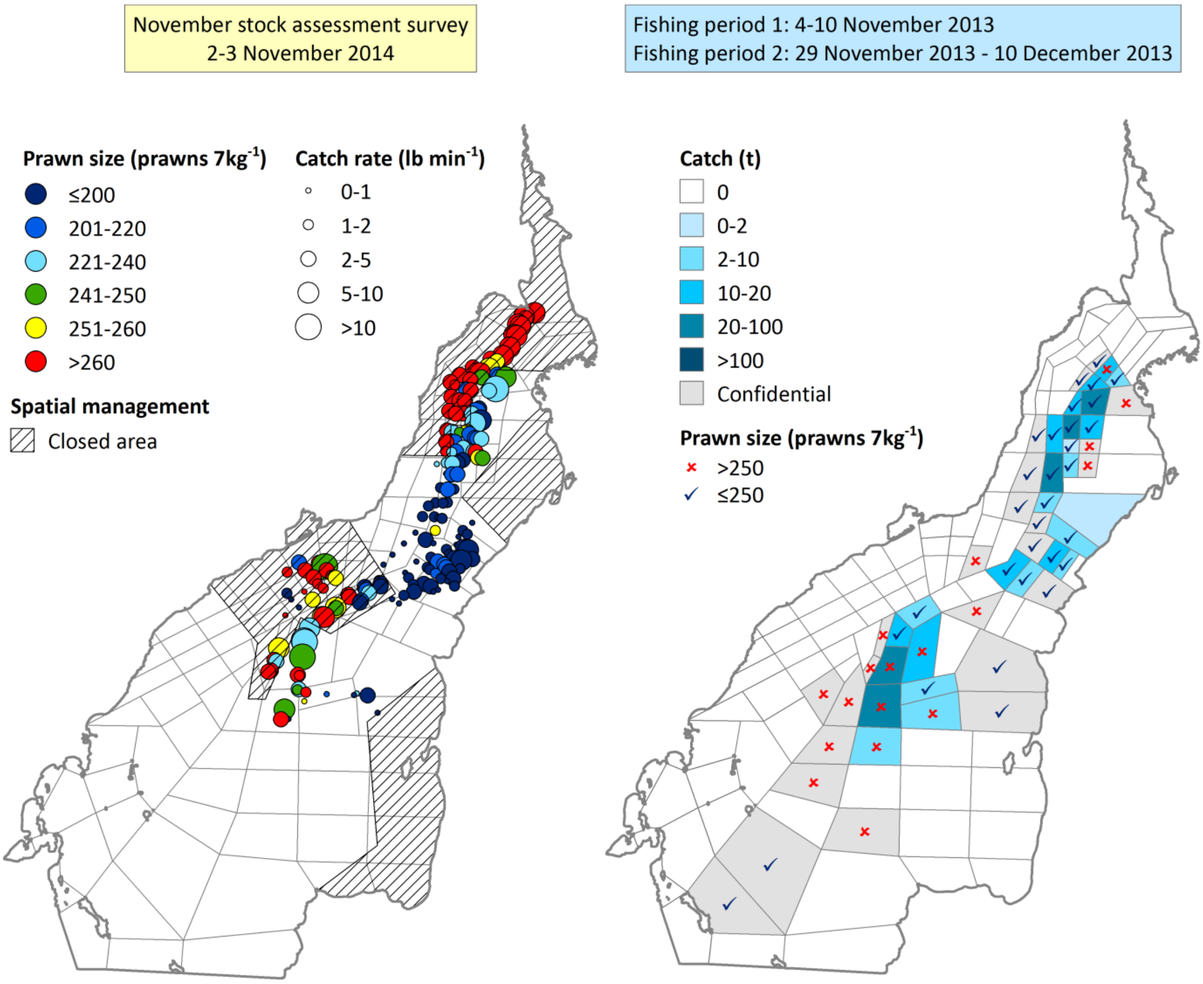

Figure A 2. Maps of the SGPF showing the November stock assessment survey results (left) and the subsequent distribution of commercial catch and fishery performance relative to size criteria (right). Hatched areas (map on left) indicate the areas closed to fishing following the survey. Blocks shaded grey (map on right) indicates less than five vessels.

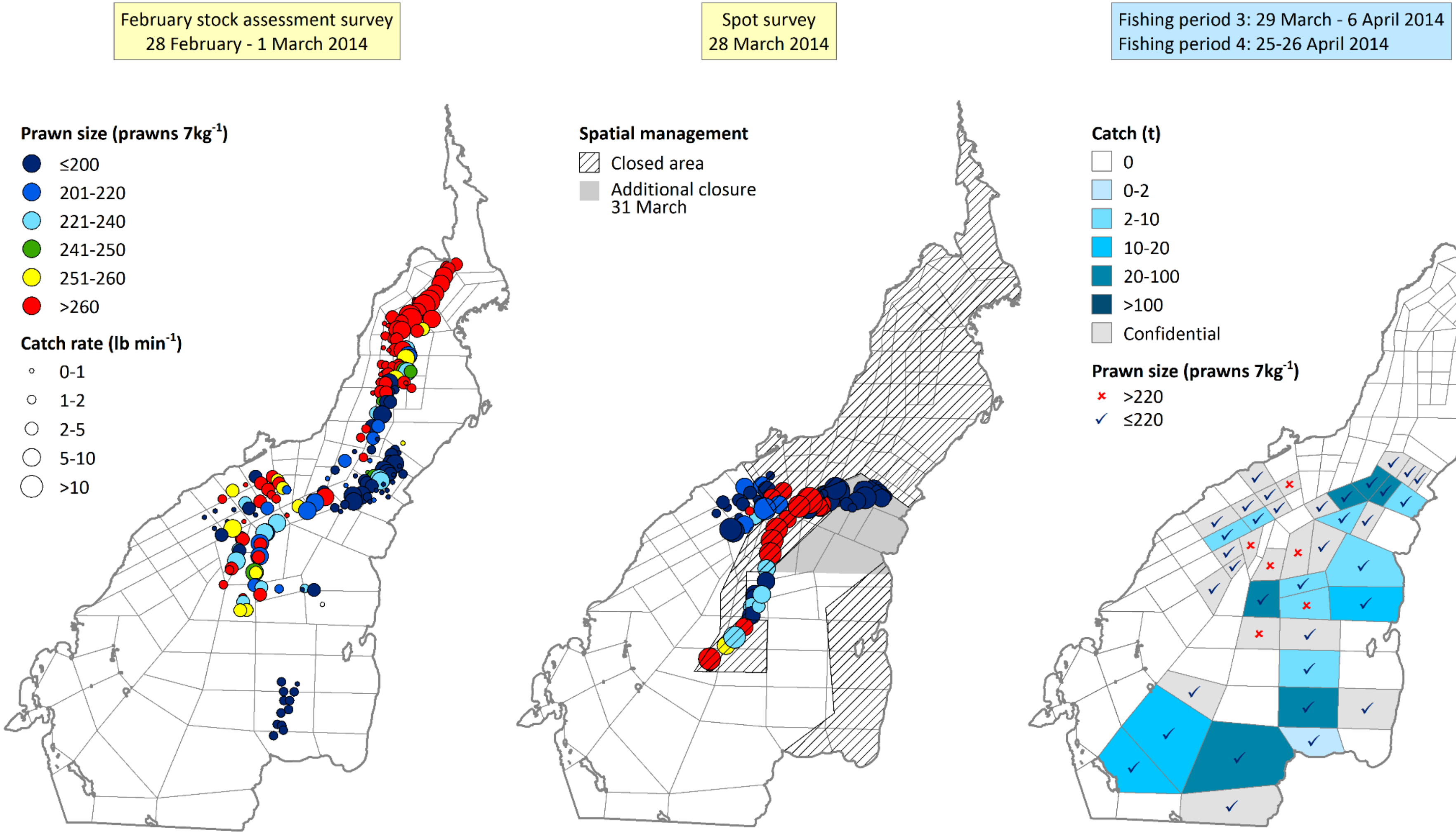

Figure A 3. Maps of the SGPF showing the February stock assessment survey results (left), March spot survey results (middle), and the subsequent distribution of commercial catch and fishery performance relative to size criteria (right). Hatched and grey areas (middle map) indicate the areas closed to fishing on 28 March and 31 March, respectively, following the spot survey. Blocks shaded grey (right map) indicates less than five vessels.

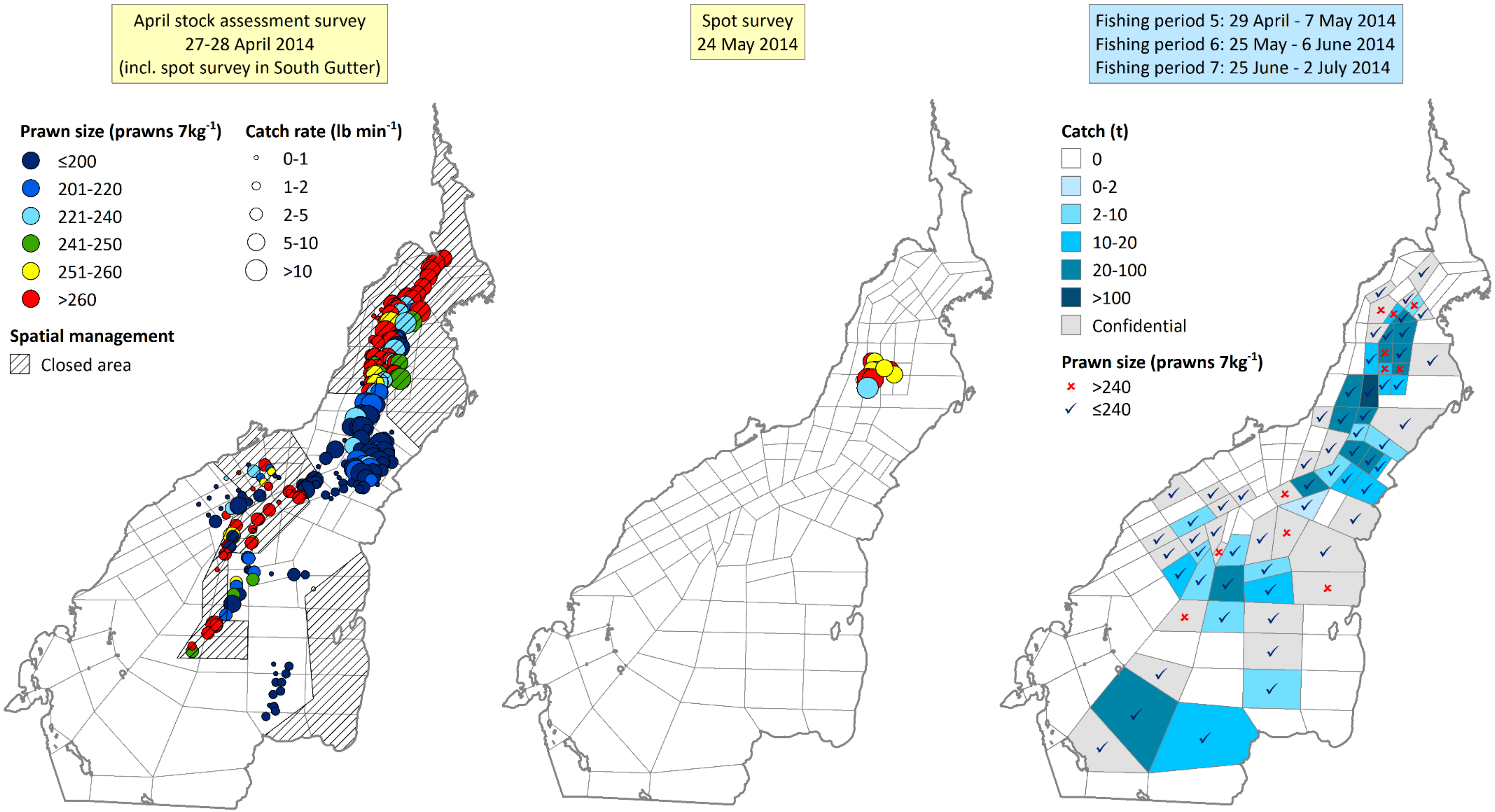

Figure A 4. Maps of the SGPF showing the April stock assessment (and spot) survey results (left), May spot survey results (middle), and the subsequent distribution of commercial catch and fishery performance relative to size criteria (right). Hatched areas (left map) indicate the areas closed to fishing following the stock assessment survey. Blocks shaded grey (right map) indicates less than five vessels.

APPENDIX B

Table B 1. Output from R of the GLM used to standardise survey CPUE, and model coefficients.

```
Call:
glm2(formula = CATCHcbrt ~ YEARSURV + REGION + VESSEL + TIDEDIR +
    LUM, family = gaussian(link = "identity"), data = d.sg, offset
    = EFFORT)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.7988  -0.5392   0.0019   0.5526   3.4922

Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)               1.805440   0.098697  18.293  < 2e-16 ***
YEARSURV2004/05_SURV2     0.573653   0.104066   5.512 3.69e-08 ***
YEARSURV2004/05_SURV3     0.892909   0.106270   8.402  < 2e-16 ***
YEARSURV2005/06_SURV1     0.396298   0.160172   2.474 0.013382 *
YEARSURV2005/06_SURV2     0.905910   0.157227   5.762 8.75e-09 ***
YEARSURV2005/06_SURV3     0.770154   0.159909   4.816 1.50e-06 ***
YEARSURV2006/07_SURV1    -0.071691   0.100400  -0.714 0.475221
YEARSURV2006/07_SURV2     0.265428   0.099602   2.665 0.007722 **
YEARSURV2006/07_SURV3     0.595580   0.099461   5.988 2.25e-09 ***
YEARSURV2007/08_SURV1     0.283505   0.099507   2.849 0.004400 **
YEARSURV2007/08_SURV2     0.335389   0.100975   3.322 0.000901 ***
YEARSURV2007/08_SURV3     0.742365   0.101540   7.311 3.01e-13 ***
YEARSURV2008/09_SURV1     0.201445   0.101613   1.982 0.047474 *
YEARSURV2008/09_SURV2     0.479565   0.098615   4.863 1.19e-06 ***
YEARSURV2008/09_SURV3     0.322996   0.102200   3.160 0.001584 **
YEARSURV2009/10_SURV1     0.219621   0.155574   1.412 0.158097
YEARSURV2009/10_SURV2     0.654011   0.154330   4.238 2.29e-05 ***
YEARSURV2009/10_SURV3     1.077452   0.099691  10.808  < 2e-16 ***
YEARSURV2010/11_SURV1     0.392016   0.101311   3.869 0.000110 ***
YEARSURV2010/11_SURV2     0.596260   0.100121   5.955 2.75e-09 ***
YEARSURV2010/11_SURV3     0.791626   0.101706   7.783 8.30e-15 ***
YEARSURV2011/12_SURV1     0.437624   0.102729   4.260 2.08e-05 ***
YEARSURV2011/12_SURV2     0.545245   0.099742   5.467 4.78e-08 ***
YEARSURV2011/12_SURV3     0.604310   0.099122   6.097 1.15e-09 ***
YEARSURV2012/13_SURV1     0.007744   0.100995   0.077 0.938882
YEARSURV2012/13_SURV2    -0.128617   0.104052  -1.236 0.216475
YEARSURV2012/13_SURV3     0.507089   0.099858   5.078 3.93e-07 ***
YEARSURV2013/14_SURV1     0.045152   0.103620   0.436 0.663037
YEARSURV2013/14_SURV2     0.223446   0.099048   2.256 0.024112 *
YEARSURV2013/14_SURV3     0.478983   0.106399   4.502 6.87e-06 ***
REGIONCPT                -0.450359   0.066304  -6.792 1.21e-11 ***
REGIONGUT                 0.659088   0.049207  13.394  < 2e-16 ***
REGIONMBK                 1.033303   0.050016  20.659  < 2e-16 ***
REGIONNTH                 1.381460   0.041322  33.431  < 2e-16 ***
REGIONSGU                -0.155144   0.071445  -2.172 0.029933 *
REGIONWAL                 0.407481   0.044031   9.255  < 2e-16 ***
REGIONWAR                -0.565031   0.089237  -6.332 2.61e-10 ***
REGIONWGU                 0.338638   0.067124   5.045 4.67e-07 ***
VESSELB                   0.339060   0.075787   4.474 7.83e-06 ***
VESSELC                   0.263635   0.117168   2.250 0.024482 *
VESSELD                   0.112374   0.075318   1.492 0.135754
VESSELE                  -0.050970   0.069157  -0.737 0.461141
VESSELF                   0.085263   0.090625   0.941 0.346830
VESSELG                  -0.062327   0.349062  -0.179 0.858293
VESSELH                   0.028997   0.069727   0.416 0.677521
VESSELI                  -0.044221   0.119179  -0.371 0.710614
VESSELJ                   0.236308   0.069603   3.395 0.000691 ***
VESSELK                   0.453894   0.070587   6.430 1.38e-10 ***
VESSELL                   0.211039   0.082533   2.557 0.010582 *
VESSELM                   0.189243   0.099343   1.905 0.056836 .
VESSELN                   0.169364   0.080370   2.107 0.035135 *
VESSELO                   0.600181   0.106138   5.655 1.64e-08 ***
VESSELP                  -0.086095   0.118266  -0.728 0.466656
VESSELQ                  -0.021445   0.178148  -0.120 0.904188
VESSELR                   0.179032   0.066443   2.695 0.007069 **
VESSELS                   0.399911   0.153759   2.601 0.009322 **
VESSELT                   0.341355   0.152731   2.235 0.025455 *
VESSELU                   0.734677   0.455398   1.613 0.106741
VESSELV                   0.170476   0.094767   1.799 0.072086 .
VESSELW                   0.282510   0.068389   4.131 3.66e-05 ***
VESSELX                   0.239993   0.071385   3.362 0.000779 ***
VESSELY                   0.264366   0.069808   3.787 0.000154 ***
VESSELZ                   0.266663   0.067017   3.979 7.00e-05 ***
TIDEDIRna                -0.168848   0.120024  -1.407 0.159545
TIDEDIRST                 0.051964   0.038059   1.365 0.172188
TIDEDIRWT                 0.265730   0.029082   9.137  < 2e-16 ***
LUM                       3.622821   0.776388   4.666 3.14e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
(Dispersion parameter for gaussian family taken to be 0.7940174)

    Null deviance: 7317.7  on 5874  degrees of freedom
Residual deviance: 4611.7  on 5808  degrees of freedom
AIC: 15386

Number of Fisher Scoring iterations: 2
```

Table B 2. Output from R of the GLM used to standardise fishery CPUE, and model coefficients.

```
Call:
glm2(formula = CATCHcbrt ~ FYEAR_MONTH + REG_ID + EFFORT +
    LIC_NO + LUM + LUMLAG7, family = gaussian(link =
    "identity"), data = d.sg)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-10.5676   -0.7855   -0.0440    0.7486   11.1563

Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)               1.568848   0.069716  22.503  < 2e-16 ***
FYEAR_MONTH1990/91_12     0.454740   0.073261   6.207 5.43e-10 ***
FYEAR_MONTH1990/91_3      1.155427   0.069529  16.618  < 2e-16 ***
FYEAR_MONTH1990/91_4      0.245464   0.076376   3.214 0.001310 **
FYEAR_MONTH1990/91_5      0.447054   0.069913   6.394 1.62e-10 ***
FYEAR_MONTH1990/91_6     -0.192666   0.074489  -2.586 0.009698 **
FYEAR_MONTH1990/91_7     -1.484302   0.119079 -12.465  < 2e-16 ***
FYEAR_MONTH1991/92_11     1.545815   0.075276  20.535  < 2e-16 ***
FYEAR_MONTH1991/92_12     0.617914   0.072719   8.497  < 2e-16 ***
FYEAR_MONTH1991/92_3      0.756783   0.069863  10.832  < 2e-16 ***
FYEAR_MONTH1991/92_4      1.452288   0.074795  19.417  < 2e-16 ***
FYEAR_MONTH1991/92_5      0.099716   0.070405   1.416 0.156685
FYEAR_MONTH1991/92_6      0.055679   0.083596   0.666 0.505384
FYEAR_MONTH1992/93_11     0.667539   0.074204   8.996  < 2e-16 ***
FYEAR_MONTH1992/93_12     0.144186   0.080859   1.783 0.074561 .
FYEAR_MONTH1992/93_3      0.248005   0.069895   3.548 0.000388 ***
FYEAR_MONTH1992/93_4     -0.264121   0.073920  -3.573 0.000353 ***
FYEAR_MONTH1992/93_5      0.720230   0.071691  10.046  < 2e-16 ***
FYEAR_MONTH1992/93_6     -1.075431   0.083303 -12.910  < 2e-16 ***
FYEAR_MONTH1993/94_11     0.703907   0.079596   8.843  < 2e-16 ***
FYEAR_MONTH1993/94_12     0.019145   0.075897   0.252 0.800851
FYEAR_MONTH1993/94_3      1.375750   0.078446  17.538  < 2e-16 ***
FYEAR_MONTH1993/94_4      1.096768   0.085536  12.822  < 2e-16 ***
FYEAR_MONTH1993/94_5      0.455605   0.071572   6.366 1.96e-10 ***
FYEAR_MONTH1993/94_6      0.425531   0.073224   5.811 6.22e-09 ***
FYEAR_MONTH1994/95_11     0.887065   0.077032  11.515  < 2e-16 ***
FYEAR_MONTH1994/95_12     0.712826   0.077688   9.176  < 2e-16 ***
FYEAR_MONTH1994/95_3      1.535765   0.072064  21.311  < 2e-16 ***
FYEAR_MONTH1994/95_4      1.831641   0.073917  24.780  < 2e-16 ***
FYEAR_MONTH1994/95_5      0.790906   0.073700  10.731  < 2e-16 ***
FYEAR_MONTH1994/95_6     -0.183723   0.087107  -2.109 0.034934 *
FYEAR_MONTH1995/96_11     1.153879   0.073553  15.688  < 2e-16 ***
FYEAR_MONTH1995/96_12     0.850714   0.078002  10.906  < 2e-16 ***
FYEAR_MONTH1995/96_3      0.731913   0.074732   9.794  < 2e-16 ***
FYEAR_MONTH1995/96_4      1.585792   0.077166  20.550  < 2e-16 ***
FYEAR_MONTH1995/96_5      0.392732   0.069717   5.633 1.78e-08 ***
FYEAR_MONTH1995/96_6     -1.454591   0.082189 -17.698  < 2e-16 ***
FYEAR_MONTH1996/97_11     0.033169   0.088678   0.374 0.708373
FYEAR_MONTH1996/97_12     0.064465   0.073692   0.875 0.381694
FYEAR_MONTH1996/97_3      0.854625   0.073571  11.616  < 2e-16 ***
FYEAR_MONTH1996/97_4      1.391345   0.079414  17.520  < 2e-16 ***
FYEAR_MONTH1996/97_5      0.747280   0.073146  10.216  < 2e-16 ***
FYEAR_MONTH1996/97_6      0.180647   0.076370   2.365 0.018012 *
FYEAR_MONTH1997/98_11     1.090809   0.078172  13.954  < 2e-16 ***
FYEAR_MONTH1997/98_12     0.490986   0.086619   5.668 1.45e-08 ***
FYEAR_MONTH1997/98_3      2.510004   0.078863  31.827  < 2e-16 ***
FYEAR_MONTH1997/98_4      3.215540   0.075052  42.844  < 2e-16 ***
FYEAR_MONTH1997/98_5      2.207923   0.069518  31.760  < 2e-16 ***
FYEAR_MONTH1997/98_6      1.694143   0.143599  11.798  < 2e-16 ***
FYEAR_MONTH1998/99_11     2.955959   0.083729  35.304  < 2e-16 ***
FYEAR_MONTH1998/99_12     1.968052   0.076470  25.736  < 2e-16 ***
FYEAR_MONTH1998/99_3      1.960555   0.075554  25.949  < 2e-16 ***
FYEAR_MONTH1998/99_4      3.423225   0.074138  46.174  < 2e-16 ***
FYEAR_MONTH1998/99_5      1.692920   0.076803  22.042  < 2e-16 ***
FYEAR_MONTH1998/99_6     -0.218684   0.108788  -2.010 0.044415 *
FYEAR_MONTH1999/00_11     1.400181   0.089928  15.570  < 2e-16 ***
FYEAR_MONTH1999/00_12     0.963843   0.074464  12.944  < 2e-16 ***
FYEAR_MONTH1999/00_3      1.411585   0.080670  17.498  < 2e-16 ***
FYEAR_MONTH1999/00_4      2.879356   0.078351  36.749  < 2e-16 ***
FYEAR_MONTH1999/00_5      1.526725   0.074423  20.514  < 2e-16 ***
FYEAR_MONTH1999/00_6      0.277129   0.086017   3.222 0.001274 **
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FYEAR_MONTH2000/01_11     0.854529   0.075467  11.323  < 2e-16 ***
FYEAR_MONTH2000/01_12     1.260909   0.080703  15.624  < 2e-16 ***
FYEAR_MONTH2000/01_3      2.469905   0.085677  28.828  < 2e-16 ***
FYEAR_MONTH2000/01_4      4.521765   0.075394  59.975  < 2e-16 ***
FYEAR_MONTH2000/01_5      2.719660   0.072092  37.725  < 2e-16 ***
FYEAR_MONTH2000/01_6      0.874758   0.087099  10.043  < 2e-16 ***
FYEAR_MONTH2001/02_11     3.202758   0.088849  36.047  < 2e-16 ***
FYEAR_MONTH2001/02_12     1.739212   0.075692  22.978  < 2e-16 ***
FYEAR_MONTH2001/02_3      1.981761   0.079272  25.000  < 2e-16 ***
FYEAR_MONTH2001/02_4      2.977866   0.075272  39.562  < 2e-16 ***
FYEAR_MONTH2001/02_5      2.359348   0.076740  30.745  < 2e-16 ***
FYEAR_MONTH2001/02_6      0.308893   0.090621   3.409 0.000653 ***
FYEAR_MONTH2002/03_11     1.741805   0.084636  20.580  < 2e-16 ***
FYEAR_MONTH2002/03_12     1.085939   0.081997  13.244  < 2e-16 ***
FYEAR_MONTH2002/03_3      1.124987   0.082070  13.708  < 2e-16 ***
FYEAR_MONTH2002/03_4      1.812804   0.075870  23.894  < 2e-16 ***
FYEAR_MONTH2002/03_5      1.116952   0.069052  16.176  < 2e-16 ***
FYEAR_MONTH2002/03_6     -0.183842   0.109565  -1.678 0.093365 .
FYEAR_MONTH2003/04_11     1.261897   0.092922  13.580  < 2e-16 ***
FYEAR_MONTH2003/04_12     1.095236   0.087838  12.469  < 2e-16 ***
FYEAR_MONTH2003/04_3      1.734339   0.073673  23.541  < 2e-16 ***
FYEAR_MONTH2003/04_4      2.952399   0.072754  40.580  < 2e-16 ***
FYEAR_MONTH2003/04_5      1.805597   0.071690  25.186  < 2e-16 ***
FYEAR_MONTH2003/04_6     -0.167657   0.082233  -2.039 0.041475 *
FYEAR_MONTH2004/05_11     1.630636   0.090753  17.968  < 2e-16 ***
FYEAR_MONTH2004/05_12     1.282982   0.074986  17.110  < 2e-16 ***
FYEAR_MONTH2004/05_3      2.092624   0.076007  27.532  < 2e-16 ***
FYEAR_MONTH2004/05_4      2.594813   0.076420  33.955  < 2e-16 ***
FYEAR_MONTH2004/05_5      1.891261   0.075742  24.970  < 2e-16 ***
FYEAR_MONTH2004/05_6      0.944583   0.081517  11.588  < 2e-16 ***
FYEAR_MONTH2005/06_11     2.032244   0.084747  23.980  < 2e-16 ***
FYEAR_MONTH2005/06_12     1.360066   0.088211  15.418  < 2e-16 ***
FYEAR_MONTH2005/06_3      3.625163   0.082444  43.971  < 2e-16 ***
FYEAR_MONTH2005/06_4      2.821912   0.080362  35.115  < 2e-16 ***
FYEAR_MONTH2005/06_5      1.437086   0.070952  20.254  < 2e-16 ***
FYEAR_MONTH2005/06_6      1.211264   0.118880  10.189  < 2e-16 ***
FYEAR_MONTH2006/07_11     1.692886   0.080070  21.143  < 2e-16 ***
FYEAR_MONTH2006/07_12     0.535525   0.082152   6.519 7.14e-11 ***
FYEAR_MONTH2006/07_3      3.023650   0.088389  34.209  < 2e-16 ***
FYEAR_MONTH2006/07_4      4.083536   0.076828  53.152  < 2e-16 ***
FYEAR_MONTH2006/07_5      2.355081   0.073974  31.837  < 2e-16 ***
FYEAR_MONTH2006/07_6      0.118630   0.088708   1.337 0.181127
FYEAR_MONTH2007/08_11     2.287384   0.088628  25.809  < 2e-16 ***
FYEAR_MONTH2007/08_12     1.506993   0.082192  18.335  < 2e-16 ***
FYEAR_MONTH2007/08_3      2.397490   0.092247  25.990  < 2e-16 ***
FYEAR_MONTH2007/08_4      3.221006   0.077271  41.685  < 2e-16 ***
FYEAR_MONTH2007/08_5      2.442794   0.073856  33.075  < 2e-16 ***
FYEAR_MONTH2007/08_6      1.006541   0.078125  12.884  < 2e-16 ***
FYEAR_MONTH2008/09_10     2.475585   0.176854  13.998  < 2e-16 ***
FYEAR_MONTH2008/09_11     1.379311   0.073442  18.781  < 2e-16 ***
FYEAR_MONTH2008/09_12     0.765940   0.107579   7.120 1.09e-12 ***
FYEAR_MONTH2008/09_2      2.516489   0.132622  18.975  < 2e-16 ***
FYEAR_MONTH2008/09_3      3.122513   0.077370  40.358  < 2e-16 ***
FYEAR_MONTH2008/09_4      2.913009   0.082059  35.499  < 2e-16 ***
FYEAR_MONTH2008/09_5      1.491472   0.067549  22.080  < 2e-16 ***
FYEAR_MONTH2009/10_11     1.625489   0.083496  19.468  < 2e-16 ***
FYEAR_MONTH2009/10_12     0.768206   0.082189   9.347  < 2e-16 ***
FYEAR_MONTH2009/10_3      3.269769   0.084485  38.702  < 2e-16 ***
FYEAR_MONTH2009/10_4      4.629868   0.074875  61.834  < 2e-16 ***
FYEAR_MONTH2009/10_5      3.151470   0.074950  42.048  < 2e-16 ***
FYEAR_MONTH2009/10_6      1.680339   0.087082  19.296  < 2e-16 ***
FYEAR_MONTH2010/11_11     3.687044   0.089696  41.106  < 2e-16 ***
FYEAR_MONTH2010/11_12     1.217845   0.089502  13.607  < 2e-16 ***
FYEAR_MONTH2010/11_3      3.130515   0.091251  34.307  < 2e-16 ***
FYEAR_MONTH2010/11_4      3.027701   0.079694  37.992  < 2e-16 ***
FYEAR_MONTH2010/11_5      2.011570   0.073276  27.452  < 2e-16 ***
FYEAR_MONTH2010/11_6      0.670672   0.084652   7.923 2.36e-15 ***
FYEAR_MONTH2011/12_10     1.907550   0.104729  18.214  < 2e-16 ***
FYEAR_MONTH2011/12_11     0.774458   0.079913   9.691  < 2e-16 ***
FYEAR_MONTH2011/12_12     1.176579   0.150493   7.818 5.43e-15 ***
FYEAR_MONTH2011/12_3      2.657299   0.083241  31.923  < 2e-16 ***
FYEAR_MONTH2011/12_4      2.826147   0.073035  38.696  < 2e-16 ***
FYEAR_MONTH2011/12_5      1.192309   0.073448  16.233  < 2e-16 ***
FYEAR_MONTH2011/12_6     -0.645646   0.093683  -6.892 5.55e-12 ***
FYEAR_MONTH2012/13_11     1.874295   0.085956  21.805  < 2e-16 ***
FYEAR_MONTH2012/13_12     1.324470   0.075085  17.640  < 2e-16 ***
FYEAR_MONTH2012/13_3      2.523518   0.100312  25.157  < 2e-16 ***
FYEAR_MONTH2012/13_4      2.416107   0.073194  33.009  < 2e-16 ***
FYEAR_MONTH2012/13_5      1.758312   0.076127  23.097  < 2e-16 ***
FYEAR_MONTH2012/13_6      0.851838   0.087586   9.726  < 2e-16 ***
FYEAR_MONTH2013/14_11     1.963270   0.082586  23.772  < 2e-16 ***
FYEAR_MONTH2013/14_12     0.975293   0.081519  11.964  < 2e-16 ***
FYEAR_MONTH2013/14_3      1.890201   0.124589  15.172  < 2e-16 ***
FYEAR_MONTH2013/14_4      1.902466   0.078860  24.125  < 2e-16 ***
FYEAR_MONTH2013/14_5      1.491820   0.073114  20.404  < 2e-16 ***
FYEAR_MONTH2013/14_6      0.739872   0.081199   9.112  < 2e-16 ***
FYEAR_MONTH2013/14_7      0.770864   0.144735   5.326 1.01e-07 ***
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REG_IDCPT                -0.764471   0.029466 -25.944  < 2e-16 ***
REG_IDGUT                 0.583029   0.028423  20.513  < 2e-16 ***
REG_IDMBK                 1.017834   0.026816  37.957  < 2e-16 ***
REG_IDNTH                 1.453761   0.029254  49.694  < 2e-16 ***
REG_IDSGU                -0.164185   0.031087  -5.282 1.28e-07 ***
REG_IDTHI                -0.578929   0.038290 -15.119  < 2e-16 ***
REG_IDWAL                 0.716836   0.025475  28.139  < 2e-16 ***
REG_IDWAR                -0.335933   0.036137  -9.296  < 2e-16 ***
REG_IDWGU                 0.248984   0.050880   4.894 9.93e-07 ***
EFFORT                    0.529315   0.001685 314.045  < 2e-16 ***
VESSEL2                   0.541271   0.047673  11.354  < 2e-16 ***
VESSEL3                   0.861958   0.042781  20.148  < 2e-16 ***
VESSEL4                   0.459056   0.044248  10.375  < 2e-16 ***
VESSEL5                   0.322695   0.045296   7.124 1.06e-12 ***
VESSEL6                   0.757517   0.043618  17.367  < 2e-16 ***
VESSEL7                   0.476234   0.046351  10.275  < 2e-16 ***
VESSEL8                   0.660128   0.043337  15.232  < 2e-16 ***
VESSEL9                   0.749487   0.046231  16.212  < 2e-16 ***
VESSEL10                  0.105065   0.043647   2.407 0.016080 *
VESSEL11                  0.451038   0.044964  10.031  < 2e-16 ***
VESSEL12                  0.355568   0.044036   8.074 6.88e-16 ***
VESSEL13                  0.464752   0.046540   9.986  < 2e-16 ***
VESSEL14                  0.621523   0.046476  13.373  < 2e-16 ***
VESSEL15                  0.493022   0.043444  11.349  < 2e-16 ***
VESSEL16                  0.857266   0.047005  18.238  < 2e-16 ***
VESSEL17                  0.090238   0.047036   1.918 0.055052 .
VESSEL18                  0.398185   0.043445   9.165  < 2e-16 ***
VESSEL19                  0.713011   0.045366  15.717  < 2e-16 ***
VESSEL20                  0.495559   0.044945  11.026  < 2e-16 ***
VESSEL21                  0.519477   0.045172  11.500  < 2e-16 ***
VESSEL22                  0.578682   0.046754  12.377  < 2e-16 ***
VESSEL23                  0.316608   0.046788   6.767 1.33e-11 ***
VESSEL24                  0.777250   0.045646  17.028  < 2e-16 ***
VESSEL25                  0.440429   0.044570   9.882  < 2e-16 ***
VESSEL26                  0.848607   0.044548  19.049  < 2e-16 ***
VESSEL27                  0.716542   0.044184  16.217  < 2e-16 ***
VESSEL28                  0.829259   0.045080  18.395  < 2e-16 ***
VESSEL29                  0.497136   0.045594  10.904  < 2e-16 ***
VESSEL30                  0.804552   0.044755  17.977  < 2e-16 ***
VESSEL31                  0.691765   0.045513  15.199  < 2e-16 ***
VESSEL32                  0.537784   0.042863  12.547  < 2e-16 ***
VESSEL33                  0.758308   0.046254  16.394  < 2e-16 ***
VESSEL34                  0.642791   0.047247  13.605  < 2e-16 ***
VESSEL35                  0.451415   0.046203   9.770  < 2e-16 ***
VESSEL36                  0.226745   0.045333   5.002 5.69e-07 ***
VESSEL37                  0.667509   0.045897  14.544  < 2e-16 ***
VESSEL38                  0.405450   0.046637   8.694  < 2e-16 ***
VESSEL39                  0.529326   0.045263  11.694  < 2e-16 ***
LUM                      -2.512084   0.037575 -66.855  < 2e-16 ***
LUMLAG7                   0.895766   0.017170  52.169  < 2e-16 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 1.616481)

    Null deviance: 397855  on 71299  degrees of freedom
Residual deviance: 114935  on 71102  degrees of freedom
AIC: 236782

Number of Fisher Scoring iterations: 2
```